NIST Technical Note 1629

# Fire Fighting Tactics Under Wind Driven Fire Conditions: 7-Story Building Experiments

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# Fire Fighting Tactics Under Wind Driven Fire Conditions: 7-Story Building Experiments

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## Abstract

In February 2008, a series of 14 experiments were conducted in a 7-story building to evaluate the ability of positive pressure ventilation fans, wind control devices and external water application with floor below nozzles to mitigate the hazards of a wind driven fire in a structure. Each of the 14 experiments started with a fire in a furnished room. The air flow for 12 of the 14 experiments was intensified by a natural or mechanical wind.. Each of the tactics were evaluated individually and in conjunction with each other to assess the benefit to fire fighters, as well as occupants in the structure.

The results of the experiments provide a baseline for the hazards associated with a wind driven fire and the impact of pressure, ventilation and flow paths within a structure. Wind created conditions that rapidly caused the environment in the structure to deteriorate by forcing fire gases through the apartment of origin and into the public corridor and stairwell. These conditions would be untenable for advancing fire fighters. Each of the tactics were able to reduce the thermal hazard created by the wind driven fire. Multiple tactics used in conjunction with each other were very effective at improving conditions for fire fighter operations and occupant egress.

Fire departments that wish to implement the tactics used in this study will need to develop training and determine appropriate methods for deploying these tactics. Variations in the methods of deployment may be required due to differences in staffing, equipment, building stock, typical weather conditions, etc. There is uniformity however, in the physics behind the wind driven fire condition and the principles of the tactics examined. The data from this research will help provide the science to identify methods and promulgation of improved standard operating guidelines (SOG) for the fire service to enhance firefighter safety, fire ground operations, and use of equipment.

The experiments were conducted by the National Institute of standards and Technology (NIST), the Fire Department of New York City (FDNY), and the Polytechnic Institute of New York University with the support of the Department of Homeland security (DHS)/Federal Emergency Management Agency (FEMA) Assistance to Firefighters Research and Development Grant Program and the United States Fire Administration.

## Disclaimer

Certain trade names or company products are mentioned in the text to specify adequately the experimental procedure and equipment used. In no case does such identification imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the equipment is the best available for the purpose.

Regarding Non-Metric Units: The policy of the National Institute of Standards and Technology is to use metric units in all its published materials. To aid in the understanding of this report, in most cases, measurements are reported in both metric and U.S. customary units.

## Acknowledgments

Experiments of this magnitude require the assistance of many individuals and cooperation of many organizations to plan and execute. To list everyone that made these experiments possible by name would be impossible. The following organizations played an important role in bringing this study to fruition and the authors can't express their gratitude enough.

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The Polytechnic Institute of New York University played a key role in documenting the structure and monitoring the weather and wind conditions during the experiments. They will continue the research on the impact of wind on fires in structures through the use of computer modeling. This effort is being lead by Dr. Sunil Kumar. The principal members of the team involved in the experiments included: Prabodh Panindre, Vishal Prajapati, Susan Mousavi, Christopher Alvarez, and Ramirez Antonio.

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While the preparation and performance of the experiments was challenging and labor intensive, the development of this report was also challenging and labor intensive. The authors wish to thank Jonathan Kent for the application of his programming talents to enabling rapid data analysis schemes and the ability to easily meld the timeline information with the numerical data on each graph.

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## Nomenclature

Text:

| | |
|---|---|
| gpm | gallons per minute |
| FBN 1 | Floor below nozzle (high rise nozzle) which is angled up from the floor below |
| FBN 2 | Floor below nozzle (high rise nozzle) with a hook that attaches to the fire floor |
| IR | Infrared |
| mph | miles per hour |
| MVU | Mobile Ventilation Unit |
| PPE | Personal Protective Ensamble |
| PPV | Positive Pressure Ventilation |
| SCBA | Self Contained Breathing Apparatus |
| WCD | Wind Control Device |

Figures:

| | |
|---|---|
| BH | Bulkhead |
| BR | Bedroom |
| double | The double window present in the bedrooms of the test apartments; unless otherwise specified, assume the window of the ignition apartment |
| LR | Living Room |
| S1 | Stairwell doorway on the 1$^{st}$ floor |
| S3 | Stairwell doorway on the 3$^{rd}$ floor |
| S5 | Stairwell doorway on the 5$^{th}$ floor |
| S7 | Stairwell doorway on the 7$^{th}$ floor |
| single | The single window present in the bedroom of the test apartments |

# Table of Contents

# Executive Summary

The National Institute of Standards and Technology (NIST), the Fire Department of New York City (FDNY), and the Polytechnic Institute of New York University with the support of the Department of Homeland Security (DHS)/Federal Emergency Management Agency (FEMA) Assistance to Firefighters Research and Development Grant Program and the United States Fire Administration (USFA), have conducted a series of wind driven fire experiments in a seven story building on Governors Island, New York.

The objective of this study was to improve the safety of fire fighters and building occupants by developing a better understanding of wind driven fires and wind driven fire fighting tactics, including structural ventilation and suppression. A series of 14 experiments were conducted to evaluate the ability of positive pressure ventilation fans (PPV), wind control devices (WCD), and exterior water application via floor below nozzles (FBN) also known as high rise nozzles to mitigate the hazards of a wind driven fire in a structure.

Each of the 14 experiments started with a fire in a furnished room. The air flow for 12 of the 14 experiments was intensified by a natural or mechanical wind. Each of the tools was evaluated individually as well and in conjunction with each other to assess the benefit to fire fighters, as well as occupants in the structure. The data collected used to examine the impact of the PPV fans, WCDs, and the exterior water application tactics were temperature, differential pressure, and gas velocity inside the structure. Each of the experiments was documented with video and thermal imaging cameras. These experiments also captured video of specific fire phenomena that are not typically observable on the fire ground.

During these experiments a public corridor and stairwell area was exposed to a wind driven, post-flashover apartment fire. The door from the apartment to the corridor was open for each of the experiments. The conditions in the corridor and the stairwell were of critical importance because that is the portion of the building that firefighters would use to approach the fire apartment or that occupants from adjoining apartments or adjacent floors would use to exit the building. Fires in high-rise buildings create unique safety challenges for building occupants and fire fighters. Smoke and heat spreading through the corridors and the stairs of a building during a fire can limit building occupants' ability to escape and can limit fire fighters' ability to rescue them. In 2002, there were 7300 reported fires in high rise structures (seven stories or more). The majority of these high rise fires occurred in residential occupancies, such as apartment buildings. In fires that originated in apartments, 92 % of the civilian fatalities occurred in incidents where the fire spreads beyond the room of origin.

All of the fires were ignited in furnished rooms of an apartment. Due to excess fuel pyrolysis/generation (lack of ventilation) the room of fire origin could not transition to flashover until windows self-vented and introduced additional fresh air with oxygen to burn. Without a wind imposed on the vented window, the fire did not spread from the room of origin and never left the apartment of origin. Even with no externally applied wind, creating a flow path from the outside, through the fire apartment into the corridor and up the stairs to the open bulkhead on the roof increased the temperatures and velocities in the corridors and in the stairwell resulting in hazardous conditions for fire fighters and untenable conditions for occupants on the fire floor and above in the stairwell.

With an imposed wind of 9 m/s to 11 m/s (20 mph to 25 mph) and a flow path through the fire floor and exiting out of the bulkhead door on the roof, temperatures in excess of 400 ºC (752 ºF) and velocities on the order of 10 m/s (22 mph) were measured in the corridor and stairwell above the fire floor. These extreme thermal conditions are not tenable, even for a firefighter in full protective gear.

These experiments demonstrated the "extreme" thermal conditions that can be generated by a "simple room and contents" fire and how these conditions can be extended along a flow path within a real structure when wind and an open vent are present. Potential tactics which could be implemented to interrupt and control the flow path are door control from inside the structure and or a WCD from the floor above the fire. From the floor below the fire, external water application was demonstrated to be effective in reducing the thermal hazard in the corridor and stairwell.

**Identify the Potential for Wind Driven Conditions.** Wind conditions should be considered as part of initial size-up of the incident. Wind conditions can vary widely in an urban environment due to wind flows around buildings, or shielding by buildings that give the perception on the ground that no significant wind is present, but another side of the building or a higher elevation in the building may be exposed to wind conditions. Wind speeds on the order of 10 mph to 20 mph are high enough to create a wind driven fire condition in the structure with an uncontrolled flow path.

If the fire has vented a window, important information can be gained by observing the behavior of the flame at the window. If the fire apartment has a high pressure relative to the outside due to an imposed wind, the flame will "pulse" out of the window to balance the overpressure. If the flames are being forced out of the window a flow path has been established through the building and the flow direction maybe favorable to interior fire fighting. If the flames are pulsing or being forced into the window, condition may not be favorable to interior firefighting and caution should be used on the approach to the fire floor. Even if flames are being forced out of adjacent windows in the fire apartment with a high amount of energy, there could still be sufficient energy flows on the fire floor to create a hazard for firefighters.

**Wind driven fire conditions** – The wind driven condition can be described as hot gases or flames flowing horizontally out of the room of fire origin. The wind driven fire condition has been described as a "blow torch" by firefighters. For our purposes, a wind driven fire condition exsisted when the fire gases were well mixed and of equally high temperature from the floor to the ceiling, on the order of at least 400 ºC (752 ºF). For this condition to occur inside a structure, the fire must be in a flow path. In these experiments the inlet to the flow path was the upwind window in the room of fire origin. The flow path then went through the aparatment, into the corridor, and exited out of the bulkhead door on the roof, via the stairwell. Without a flow path, the wind driven fire condition inside the structure can not occur.

**Door Control.** Door control is the most basic means to interrupt or control the flow path in the building. The fire floor stair door should be checked for heat or hot gases flowing around the edges. The door should only be opened a few inches at first to look for rapid changes in smoke volume or velocity and/or thermal conditions. If the thermal environment changes quickly, close the door to interrupt the flowpath. In a smoke filled environment, visual changes to conditions may not be apparent with out a thermal imager. A similar approach would be used on the door to the fire apartment.

**Impact of PPV.** PPV fans alone could not overcome the effects of a wind driven condition. However when used in conjunction with door control, WCDs, and FBNs, the PPV fans were able to maintain tenable and clear conditions in the stairwell. The key to successful use of PPV fans was to mitigate the wind driven fire condition via door control or other tactics. Then the PPVs can be used to clear the stair and then pressurize the stairwell to provide a safe working environment. Although the PPV fans, when used alone, could not reverse the flow of a wind driven fire, PPV fans always improved conditions in the stairwell.

**Impact of WCDs**. In these experiments, the WCDs reduced the temperatures in the corridor and the stairwell by more than 50 % within 120 s of deployment. The WCDs also completely mitigated any velocity due to the external wind. The WCDs were exposed to a variety of extended thermal conditions without failure.

**Impact of externally applied water**. In these experiments, the externally applied water streams were implemented in different ways; a fog stream inserted into the fire room window, a fog stream flowed from the floor below into the fire room window opening, and a solid water stream flowed from the floor below into the fire room window opening. In all cases, the water flows suppressed the fires, thereby causing reductions in temperature in the corridor and the stairwell of at least 50 %. The water flow rates used in these experiments were between 125 gpm and 200 gpm, demonstrating that a relatively small amount of water applied directly to the burning fuels can have a significant impact.

**Stored Energy.** Wind driven fire conditions can generate and transfer energy throughout the flow path. When doors or WCDs are used to stop the wind driven fire conditions, energy and fuel may be trapped on the fire floor. These experimental results indicate that the thermal conditions due to the residual heat on the fire floor were still of a level which could pose a hazard to firefighters in full PPE. However, when used in combination with PPV fans to force cool air into the stairwell and out through the fire floor, and or with the cooling effect from water streams, the fire floor temperatures were reduced to tenable conditions for fire fighters in full PPE in minutes.

The data from this research will help provide the science to identify methods and promulgation of improved standard operating guidelines (SOG) for the fire service to enhance firefighter safety, fire ground operations, and use of equipment. If the demonstrated technologies continue to prove effective in the field trials and pilot programs, the next step may be to examine the need for standards and standardized test methods to define a minimum level of acceptable performance of these devices.

# 1 Introduction

The National Institute of Standards and Technology (NIST), the Fire Department of New York City (FDNY), and the Polytechnic Institute of New York University with the support of the Department of Homeland Security (DHS)/Federal Emergency Management Agency (FEMA) Assistance to Firefighters Research and Development Grant Program and the United States Fire Administration (USFA), have conducted a series of wind driven fire experiments in a seven story building on Governors Island, New York. The experiments were conducted in February 2008.

The objective of this study was to improve the safety of firefighters and building occupants by enabling a better understanding of wind driven firefighting tactics, including structural ventilation and suppression. This was achieved by investigating technical issues that address the teaching of the dynamics of fire phenomena and prediction of fire intensity and growth under wind driven conditions. The data from this research will also help to identify methods and promulgation of improved standard operating guidelines (SOG) for the fire service to enhance firefighter safety, fire ground operations, and use of equipment.

A series of 14 experiments were conducted in a seven story building to evaluate the ability of positive pressure ventilation fans (PPV), wind control devices (WCD) and floor below nozzles (FBN) to mitigate the hazards of a wind driven fire in a structure. Each of the 14 experiments started with a fire in a furnished room. The air flow for 12 of the 14 experiments was intensified by a natural or mechanical wind.. Each of the tools was evaluated individually as well and in conjunction with each other to assess the benefit to fire fighters, as well as potential occupants in the structure.

These field experiments followed a series of experiments that were conducted in NIST's Large Fire Facility from November 2007 through January 2008. The NIST laboratory experiments demonstrated and quantified the impact of wind on a fire in a structure and the impact of WCDs and externally applied water streams on mitigating the hazard from a wind driven fire. The experiments were conducted in a laboratory in order to provide the best levels of control on the experiments and have the capability of making heat release rate and high quality gas concentration measurements which would be difficult and cost prohibitive to make in an acquired structure in the field. The laboratory experiments are fully documented in the report, "Fire Fighting Tactics Under Wind Driven Conditions: Laboratory Experiments"[1].

As implied by the title, the laboratory experiments were only one portion of the research needed to fully analyze the impact of wind on a fire resistive structure fire and demonstrate potential methods (tactics) for improving firefighter safety and effectiveness. The experiments on Governors Island were required to examine the effects of natural ventilation (door control) and PPV on the fire and the means of egress in the building alone and in conjunction with the use of WCDs and FBNs. Tactics incorporating devices, such as WCDs, to control the ventilation conditions or the use of a special fire nozzle from the floor below the fire floor have been tried by the fire service under "real fire" conditions with varying levels of success. Unfortunately, there is no data to understand the capabilities and limitations of these fire fighting approaches. This study provides real scale data, to guide the development of appropriate tactical operations for use under wind driven conditions.

## 1.1 Background

Fires in high-rise buildings create unique safety challenges for building occupants and fire fighters. Smoke and heat spreading through the corridors and the stairs of a building during a fire can limit building occupants' ability to escape and can limit fire fighters' ability to rescue them. In 2002, there were 7300 reported fires in high rise structures (structures 7 stories or more). The majority of these high rise fires occurred in residential occupancies, such as apartment buildings. In fires that originated in apartments, 92 % of the civilian fatalities occurred in incidents where the fire spreads beyond the room of origin [2].

Changes in the building's ventilation, such as the opening of doors or windows can increase the growth of the fire and allow it to spread beyond the room of fire origin. This can also increase the spread of fire gases through the building. In some cases, such as the Cook County Administration Building fire in October 2003, the fire flow into the corridors and the stairway prevented fire fighters from suppressing the fire from inside the structure. This fire resulted in 6 building occupant fatalities and several fire fighter injuries in the stairway [3].

The failure of a window in the fire apartment in the presence of an external wind can create significant and rapid increases in the heat production of a fire. Combined with open doors to corridors, stairs, or downwind apartments, many wind driven fire incidents have resulted in fire fighter fatalities and injuries [4, 5].

### 1.1.1 Historical Wind Driven Fires

Recognition of wind driven fire conditions has been taken into account in forest fires and large area conflagrations for more than 100 years. This is due in part to the fact that some of the most destructive and deadly conflagrations in the United States such as the Great Pestigo, WI fire and the Great Chicago fire were wind driven events. Both of these fires started on the same day, October 8, 1871. The Pestigo fire resulted in 1152 fatalities and more than 1.2 million acres burned. The Chicago fire resulted in more than 250 fatalities, and 17400 structures destroyed over a 2000 acre area [6].The magnitude of these fires was, in part, the result of strong south winds combined with "tinder dry" conditions [7].

While wildland fire managers and officers training includes weather conditions in their evaluation of incident conditions (size-up), typically structural firefighters and fire officers do not receive this type of training [8, 9, 10, 11]. Wildland fire fighter training manuals dedicate almost half of their fire behavior chapter to weather with significant sections on wind [12]. Structural fire fighter training manuals, which are approximately 1000 pages in length, dedicate a page or less to the interaction of wind and structural fire behavior [13, 14, 15]. As a result, structure fires that may have been affected by wind conditions have typically not been recognized as such or well documented, with some notable exceptions. A few such exceptions are presented in the following sections.

### 1.1.2 Experience of the Fire Department of New York City

The Fire Department of New York City (FDNY) began to recognize that wind driven fires, particularly those in multiple story, residential occupancies of fire resistive construction (Class I) were challenging their resources, their tactics, and their safety. Norman and Tracy and others in the department began to look at the challenges and results of wind driven fires, with the goal of changing the tactics in order to improve the safety and effectiveness of their members [16, 17, 18]. A listing of notable FDNY wind driven fire incidents is given in Table 1.1-1 [16, 19]. While it might appear that the frequency of occurrence has increased, the reality may be that the recognition of wind driven fires has increased in the department. In fact, the FDNY has developed a training DVD, *Fighting Wind Driven Fires in High Rise Multiple Dwellings*, which was created in November of 2007 with the objective of developing an awareness for wind effects in a structure, and identifying how to control the hazard or find shelter from the hazard by controlling doors and preparing areas of refuge [20].

Another factor Norman [16] identifies is that the fire does not have to be 20 stories or more above ground for wind to be a factor. Table 1.1-1 demonstrates that these FDNY wind driven fire incidents have occurred as low as the $3^{rd}$ story above ground. NFPA data shows that the majority of fires in high rise buildings occur below the $7^{th}$ floor [2].

**Table 1.1-1. FDNY Wind driven fire incidents.**

| Date | Location | Victims | Stories | Fire Floor |
|---|---|---|---|---|
| 1/23/80 | 30 Montrose Avenue, Brooklyn | 1 civilian fatality | 16 | $11^{th}$ |
| 2/11/89 | 23 Horace Harding Expressway, Queens | 3 civilian fatalities | 16 | $14^{th}$ |
| 11/2/94 | Park Ave, Bronx | 2 civilian fatalities | 20 | $18^{th}$ |
| 1/5/96 | 40-20 Beach Channel Drive, Queens | 1 firefighter fatality | 13 | $3^{rd}$ |
| 1/7/97 | 1 Lincoln Place, Manhattan | 18 firefighters injured | 42 | $28^{th}$ |
| 12/18/98 | 77 Vandalia Avenue, Brooklyn | 3 firefighter fatalities | 10 | $10^{th}$ |
| 12/23/98 | 124 West $60^{th}$ st, Manhattan | 4 civilian fatalities, 9 firefighters injured | 51 | $19^{th}$ |
| 4/23/01 | Waterside Plaza, Manhattan | 30 firefighters injured, 4 civilians injured | 37 | $24^{th}$ |
| 9/9/04 | 20 Confucious Place, Manhattan | 12 firefighters burned | 44 | $37^{th}$ |
| 1/26/06 | 40-20 Beach Channel Drive, Queens | 3 firefighters burned | 13 | $6^{th}$ |
| 2/26/06 | 20 Moshulu Parkway, Bronx | 3 firefighters burned | 41 | $24^{th}$ & $25^{th}$ |
| 1/03/08 | 1700 Bedford Avenue, Brooklyn | 1 firefighter fatality 4 firefighters burned, 4 civilians injured | 25 | $14^{th}$ |
| 3/28/08 | Grand Avenue, Manhattan | 1 civilian fatality, 45 injured | 26 | $4^{th}$ |
| 4/2/08 | Sutter Ave, Brooklyn | 3 firefighters injured | 22 | $5^{th}$ |

Other wind related fire fighter line of duty deaths have occurred in New York City in smaller buildings of ordinary construction (Type III) such as the "Black Sunday Fire." This fire started on the third story of a four story apartment building. The average wind speed was 12 mph with gusts up to 45 mph. Fire fighters searching for victims on the floor above the fire reported that, “fire was blowing into the hallway.” The rapid spread of fire to the 4th floor left 6 firefighters trapped. Their only option was to deploy out of the windows to ground, resulting in the death of two of the firefighters and serious injuries to the other four [21].

Buildings and topographical features alone or in combination deflect wind and as a result cause changes in wind speed and direction or localized wind effects around a building. In cities, this may be referred to as “building-spawned” wind. All buildings, regardless of size, can block wind, which may cause “local areas of amplified winds around corners and enhanced turbulence in building wakes” [22]. When wind hits the face of a structure it will seek the path of least resistance to move around it. For a multi-story building with a flat face on the upwind side, it has been demonstrated that some of the wind will go over the building, a portion of the wind will go around the building and a portion of the wind will be deflected downward, and develop a vortex near the ground. [23].

### 1.1.3 U.S. Wind Driven Fire Experience

These wind driven fire incidents are not limited to New York City. Houston, TX., st. Louis, MO., and Prince William County, VA. are just a few of the other localities in the United States that have experienced losses to wind driven fires [5, 24, 25, 26]. These incidents ranged from a fire that started on the 5th floor of a 41 story, fire resistive building to a fire that started on the wood deck outside a two story, wood frame, single family home.

Recently a near miss was documented in a wood frame Cape Cod-type house in Long Island, NY. Firefighters working to extinguish the fire, making entry from the front of the house, had flames pushed over them by the wind entering the structure from the rear [27].

A search of the National Fire Fighter Near-Miss Reporting system database also shows a variety of fire incidents and structures where wind caused a significant change in fire conditions resulting in rapid increases in thermal hazard to the fire fighters [28, 29, 30, 31, 32, 33, 34].

### 1.1.4 Wind Driven Tactics Research

What tactics or tools are appropriate for use with a wind driven fire and how should the tactics or tools be implemented? In order to answer this question, the problem has to be fully defined. The wind driven fire hazard that has been examined occurs in a high rise building of fire resistive construction with internal corridors and interior stairs. The Vandalia fire incident in which three FDNY fire fighters died exemplifies scenarios which result in untenable conditions in a public corridor. The door to the fire apartment was left open. As a result, there was nothing to keep the fire or the smoke contained in the apartment of fire origin. A door to a stair was opened and the stair was vented to the outside or an apartment on the downwind side of the building is opened. If the fire apartment was on the upwind side of the building and the window failed a ventilation path would be in place for flames to sweep through the apartment of origin and out into the corridor, making it impossible and untenable for firefighters to approach the fire apartment.

Norman summarizes tactics that FDNY has researched to address this condition, 1) breaching, 2) suppressing the fire with an exterior water stream, and 3) controlling the flow of wind into the fire apartment with a window fire blanket or curtain [16]. Breaching involves making a hole from a protected stair and continuing to breach walls until a hole for a hoseline can be made in the wall of the fire apartment or the fire could be attacked from an adjoining balcony. Exterior hose streams have been used when the fire apartment is in reach of an aerial apparatus stream. For apartments on higher floors, an applicator pipe or Navy fog applicator may be used to apply water into the window of a fire apartment on the floor above. The use of a wind control device deployed from the floor above the fire floor to block an open window to a fire apartment on the upwind side of the building has been researched by FDNY. In fact, the department issued wind control devices to special Operations Units [16].

Positive Pressure Ventilation (PPV) is being used by fire departments on smaller structures, such as single family homes, to control the fire flow by introducing pressure from the front door and venting the house through a strategic exit opening. If done correctly, this tactic can remove significant amounts of heat and smoke from the structure, thus improving the fire fighters' working environment and improving the chances of survival for the building occupants. NIST has completed several studies which have a two fold impact: 1) providing guidance on the safe use of PPV and 2) characterizing and validating the modeling of PPV with a computational fluid dynamics (CFD) model, so that the model can be used as a training tool for the fire service [35, 36, 37, 38].

In 2006, NIST research began to examine the use of PPV in high-rise firefighting. To accomplish this task, NIST partnered with the Chicago Fire Department (CFD), FDNY and the Toledo Fire and Rescue Department. In a vacant 30-story high-rise in Toledo, the capability of PPV to pressurize the stair was demonstrated in an extensive series of pressure experiments [39]. This study was followed with a series of fire experiments conducted in a 16-story high-rise in Chicago [40]. The results of the fire experiments demonstrated the ability of properly sized and placed PPV fans to pressurize stairways in a high rise building and clear them of heat and smoke even with post-flashover fires open to the corridor on the fire floor. Near the end of the test series in Chicago, experiments were conducted to examine the impact of wind on an apartment fire and the potential for a wind control device and/or a large PPV fan to control the hazard and protect the corridor. The experiments conducted on the 3rd floor demonstrated that introducing a wind to a post flashover room fire can result in "blow torch" flames through the apartment and into the corridor in less than 30 s. The experiments also showed that a wind control device could in fact negate the impact of the wind and that PPV fans may have a role in mitigating the hazard from wind driven fires.

In November 2007, the National Institute of Standards and Technology, with the support of the Fire Protection Research Foundation and the U.S. Fire Administration, began conducting eight fire experiments to examine the impact of wind on fire spread through a multi-room structure and examine the capabilities of wind-control devices (WCD) and externally applied water to mitigate the hazard. The principle measurements used to examine the impact of the WCDs and the external water application tactics were heat release rate, temperature, heat flux, and velocity inside the structure. Measurements of oxygen, carbon dioxide, carbon monoxide, total hydrocarbons and differential pressures were also measured in the bedroom (room of fire origin) and in a furnished living room (room in the flow path). Each of the experiments was recorded with video and thermal imaging cameras.

The experiments were designed to expose a public corridor area to a wind driven post-flashover apartment fire. The door from the apartment to the corridor was open for each of the experiments. The conditions in the corridor were of critical importance because that is the portion of the building that firefighters would use to approach the fire apartment or that occupants from an adjoining apartment would use to exit the building.

The fires were started in the bedroom of the apartment. Prior to the failure or venting of the bedroom window, which was on the upwind side of the experimental apartment, the heat release rate from the fire was on the order of 1 MW. After window failure, but prior to implementing either of the mitigating tactics, the heat release rates from the post-flashover structure fire were typically between 15 MW and 20 MW. When the door from the apartment to the corridor was open, temperatures in the corridor area near the open doorway, 1.52 m (5.00 ft) below the ceiling, were in excess of 600 °C (1112 °F) for each of the experiments. The heat fluxes measured in the same location, during the same experiments, were in excess of 70 kW/m². These extreme thermal conditions are not tenable, even for a firefighter in fully protective gear. These conditions were attained within 30 s of the window failure.

In these experiments, the WCDs reduced the temperatures in corridor outside the doorway by more than 50 % within 60 s of deployment. The heat fluxes were reduced by at least 70 % during this same time period. The WCDs also mitigated completely any gas velocity due to the external wind.

The externally applied water streams were implemented in three different ways; a fog stream across the face of the window opening, a fog stream into the window opening, and a solid water stream into the window opening. The fog stream across the window was not effective at reducing the thermal conditions in the corridor. The fog stream in the window decreased the corridor temperature by at least 20 % and the corresponding heat flux measures by at least 30 %. The solid streams experiments resulted in corridor temperature and heat flux reductions of at least 40 % within 60 s of application. None of the water applications had a significant impact on reducing the gas velocities in the structure. In some cases the gas velocity increased during water application.

These experiments demonstrated that the two potential tactics which could be implemented from either the floor above the fire, in the case of a WCD, or from the floor below the fire, in the case of external water application, were demonstrated to be effective in reducing the thermal hazard in the corridor.

The experiments documented below, conducted in a seven story building, analyzed the impact of wind on actual structure fire and demonstrate potential tactics for improving firefighter safety and effectiveness.

## 1.2 Structure

The experiments were conducted in a 7-story fire resistant residential apartment building located on Governors Island in New York Harbor, south of Manhattan and west of Brooklyn. This location was important due to the prevailing winds during the winter months. The structure was located on the northwestern side of the island as shown in Figure 1.2-1. The structure was “dog bone” shaped and was constructed of concrete block with concrete slab floors. Each elevation of the structure can be seen in Figure 1.2-2 through Figure 1.2-5. More detailed drawings with dimensions are located in Appendices Appendix A – Detailed Drawings.

The structure was symmetric about the fire wall in center of the building. Each side had 6 apartments (A through F and G through L), a scissor stairwell and an elevator bank. There were no openings between the two sides of the structure; therefore they were treated as two separate experimental volumes for the analysis. The floor plan was the same for floors 2 through 7. For the experiments, the first floor had all of the apartments and storage rooms sealed off and only utilized the lobby and the stairwells. All four stairways extended up above the seventh floor and had a bulkhead doorway that opened up to the roof. A detail view of the scissor stairwell can be seen in Figure 1.2-7. Opening the bulkhead door was important for flow path control of smoke and hot gases.

Apartments A, E, G and K were furnished and utilized for the experiments. Apartments A and G were two bedroom apartments with a living room, kitchen and bathroom. Apartments E and K were three bedroom apartments with a living room, kitchen and bathroom. In each of the experiments the kitchen and bathroom were walled off with gypsum board to minimize the amount of overhaul that was required between experiments. Figure 1.2-8 shows the experimental floor plan with the areas of the building that were not utilized removed for clarity. The doors to the apartments not utilized for the experiments always remained closed.

All of the walls in the apartments were made of painted gypsum board and the walls in the public corridors and stairwells were painted concrete block. All of the doors to the apartments were steel and all of the doors to the bedrooms were hollow core wood doors. The doors to the bedrooms being used for the experiments were left open as well as the fire apartment entrance door. The opening and closing of other doors was noted in the timelines.

All of the windows were double pane in aluminum frames. In the bedrooms used for ignition, there were two windows, referred to as a “double” window with 4 pane sections and a “single” window with two pane sections. The double window was closest to the point of ignition and in the wind driven experiments was on the upwind side. Each of the pane sections in the double window measured 0.61 m (2.00 ft) wide and 0.53 m (1.75 ft) high. The single window was located on the adjacent exterior wall. Each of the two pane sections, an upper and lower, measured 0.71 m (2.33 ft) wide and 0.53 m (1.75 ft) high.

The living room had a larger window which was divided in to 5 glass sections, a single pane center section with a windows on each side that had an upper and lower pane section The glass pane area of the center section measured 0.83 m (2.71 ft) wide and 1.22 m (4.00 ft) high. Each of the side panes measured 0.56 m (1.83 ft) wide and 0.53 m (1.75 ft) high.

The distance between the floor and the lower edge of the glass portion of all of the windows in the bedrooms and the living rooms was 0.91 m (3.00 ft). The dimensions of overall window frames and window openings in the brick façade are provided in the detailed drawings in Appendix A.


**Figure 1.2-1. Governors Island Map (Experimental Structure Circled)**

**Figure 1.2-2. Front of structure (Side A)**

**Figure 1.2-3. Left side of structure (Side B)**

**Figure 1.2-4. Rear of structure (Side C)**

**Figure 1.2-5. Right side of structure (Side D)**

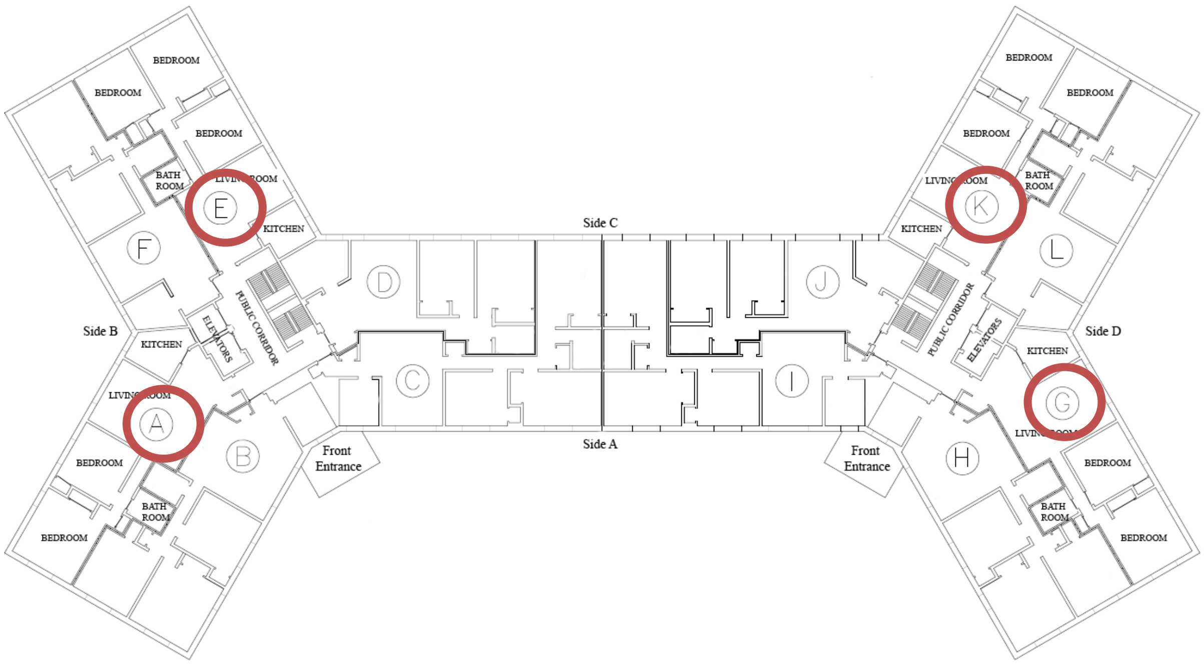



**Figure 1.2-6. Floor Plan for Floors 2-7 (Fire Apartments Circled)**

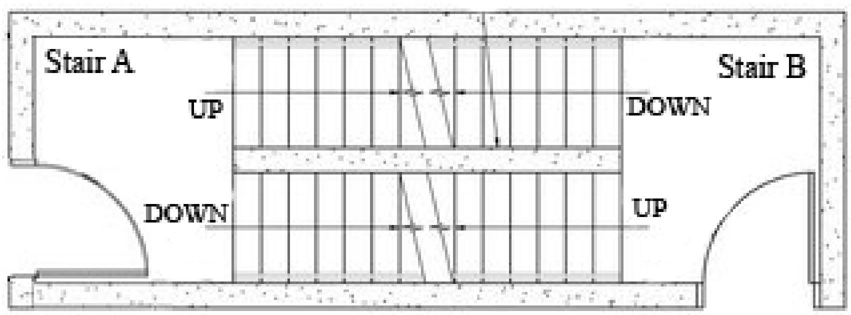



**Figure 1.2-7. Detail of scissor stairs**

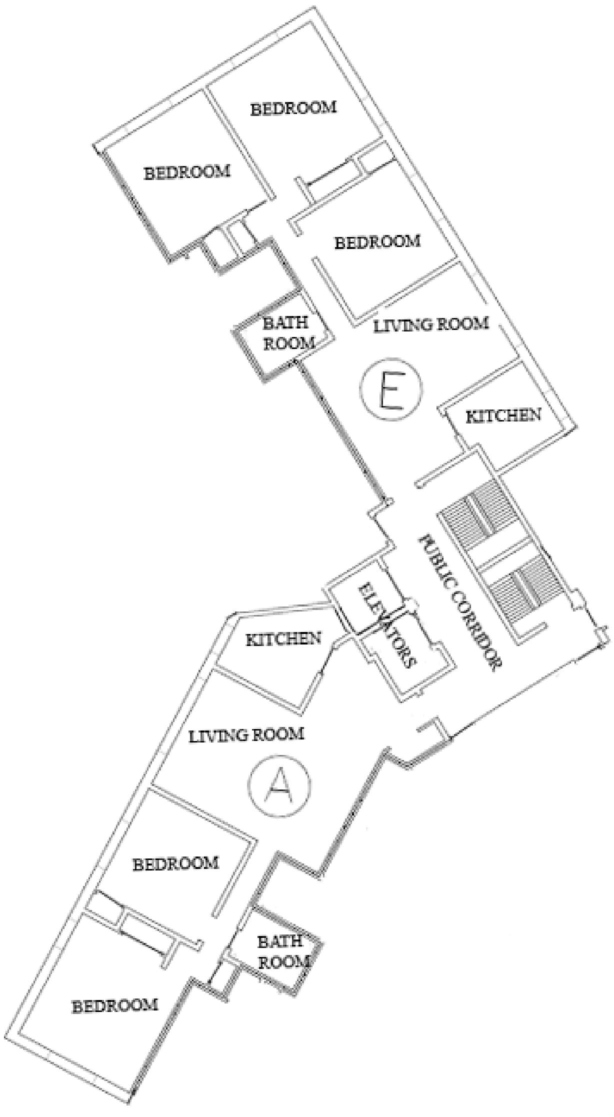



**Figure 1.2-8. Cut Away View of Experimental Area**

## 1.3 Wind

The wind for these experiments was essential. Ideally the natural wind would be sufficient to create the wind driven fire conditions for the experiments. Historically and during previous site visits the natural wind was from the desired direction at the desired magnitudes. Unfortunately the natural wind was not present during the week in which these experiments were scheduled and the option of waiting for the right wind was not an acceptable. There was one experiment in which the natural wind was sufficient and that was the experiment in Apartment 3G/K.

The direction and magnitude of the wind was measured in multiple locations by representatives of Polytechnic University. They had anemometers on and around the structure to measure the prevailing winds prior to the experiments for planning purposes and during the experiments. Their data can be found in Appendix C – Wind Measurements and Descriptions.

Because natural wind was not available, wind was created mechanically with the use of a Mobile Ventilation Unit (MVU). The MVU was a 1.2 m (48 in) gasoline powered fan that was able to provide a simulated 9 m/s to 11 m/s (20 mph to 25 mph) wind that was repeatable for all of the experiments (Figure 1.3-1 through Figure 1.3-3).

The MVU was secured to a lift which was able to position the fan as high as the $7^{th}$ floor to allow the simulated wind to be directed straight into the desired opening. The MVU was positioned 4 m to 8 m from the opening and the fan speed was adjusted to achieve the 9 m/s to 11 m/s (20 mph to 25 mph) wind in the opening. The MVU was positioned to be centered on the opening and varied slightly based on the obstructions around the building and the terrain.


**Figure 1.3-1. MVU on Lift**

**Figure 1.3-2. MVU Positioned at Window**


**Figure 1.3-3. Close-up View of MVU**

## 1.4 Fuel Load

The fuel load was comprised of common items that may be found in an apartment building. The corner bedroom and the living room of each of the apartments utilized (A, E, G and K) were furnished. Apartments G and K had a second bedroom furnished (Figure 1.2-8). The bedrooms had an average fuel load of 21 kg/m$^2$ (4.3 lb/ft$^2$) and the living rooms had an average fuel load of 15 kg/m$^2$ (3.1 lb/ft$^2$). This accounted for the combustible furnishings and not the metal objects such as the bed frames or lamps. The combustible wood floor was also not included in these averages. Table 1.4-1 shows all of the items used and their respective labels. Figure 1.4-1 through Figure 1.4-4 show the floor plan and layout of the fuel load items. In these figures the fuel load items are labelled letters that correspond to Table 1.4-1. For example, the bed in each bed room is labeled “a-e”. This means that items a through e from Table 1.4-1 are co-located in that position. In this example the mattress, box spring, head board, bedding and pillows are used for the bed fuel package. Figure 1.4-5 through Figure 1.4-32 show photographs of each apartment and the fuel load arrangement. These figures are representative of the similar layouts for each floor. For example the layout for Apartment 7A is similar to 5A and 3A.

**Table 1.4-1. Fuel Load Labels and Description**

| Label | Item | H (m) | W (m) | D (m) | Materials | Mass (kg) |
|---|---|---|---|---|---|---|
| A | Mattress | 0.2 | 1.5 | 2.0 | fiber pad/polyurethane foam | 30.4 |
| B | Box spring | 0.2 | 1.5 | 2.0 | wood / felt | 31.7 |
| C | Head Board | 1.1 | 1.4 | 0.0 | wood | 17.3 |
| D | Bedding * | 2.6 | 2.0 | - | cotton/polyester | 5.0 |
| E | Pillows -2 | 0.3 | 0.7 | 0.1 | cotton/polyester | 1.0 |
| F | Upholstered Chair (Brown) | 0.7 | 0.7 | 0.7 | polyurethane foam/wood | 24.1 |
| G | Upholstered Chair (Red) | 0.8 | 0.9 | 0.9 | polyurethane foam/wood | 28.9 |
| H | Chair (Red w/ wood arms) | 0.8 | 0.6 | 0.8 | polyurethane foam/wood | 14.5 |
| I | Desk Chair (Green) | 1.1 | 0.6 | 0.6 | polyurethane foam/wood | 16.7 |
| J | Desk Chair (Brown) | 0.7 | 0.4 | 0.4 | wood | 7.0 |
| K | Coffee Table | 0.6 | 0.6 | 0.5 | particle board/wood | 9.7 |
| L | Desk (Dark Brown w/ blue) | 0.8 | 1.3 | 0.8 | particle board/wood | 29.9 |
| M | Desk (Light Brown) | 0.8 | 1.1 | 0.6 | particle board/wood | 26.4 |
| N | Dresser (Dark Brown) | 0.8 | 1.5 | 0.5 | particle board/wood | 80.9 |
| O | Dresser (Light Brown) | 0.6 | 1.8 | 0.5 | particle board/wood | 73.3 |
| P | Nightstand (Light Brown) | 0.6 | 0.5 | 0.4 | particle board/wood | 20.9 |
| Q | Nightstand (Dark Brown) | 0.6 | 0.7 | 0.5 | particle board/wood | 32.6 |
| R | Round Table | 0.6 | 0.7 | 0.7 | particle board/wood | 12.1 |
| S | Sofa | 0.9 | 1.8 | 1.0 | polyurethane foam/wood | 53.0 |
| T | TV (Small) | 0.4 | 0.7 | 0.4 | Plastic | 23.3 |
| U | TV (Large) | 0.6 | 0.7 | 0.5 | Plastic | 36.9 |
| V | Trash Can | - | - | - | Plastic | 0.3 |

* nominal H and W area of sheets and comforter

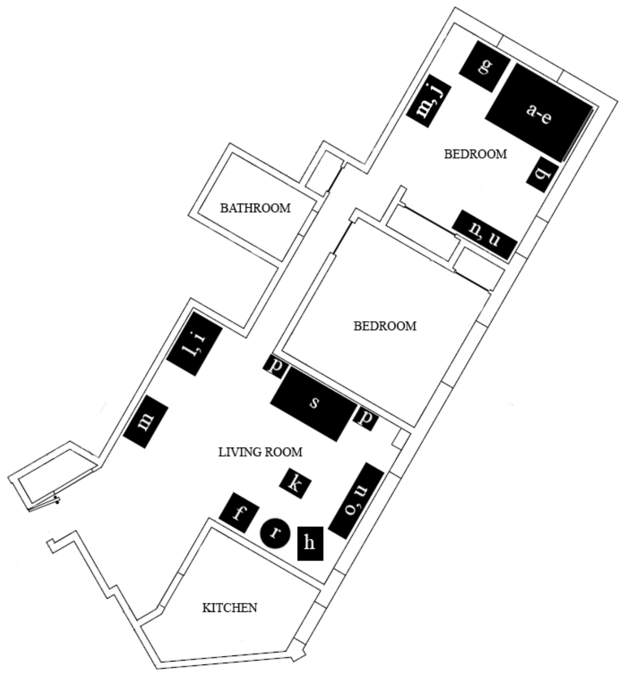



**Figure 1.4-1. Apartment A Fuel Layout**

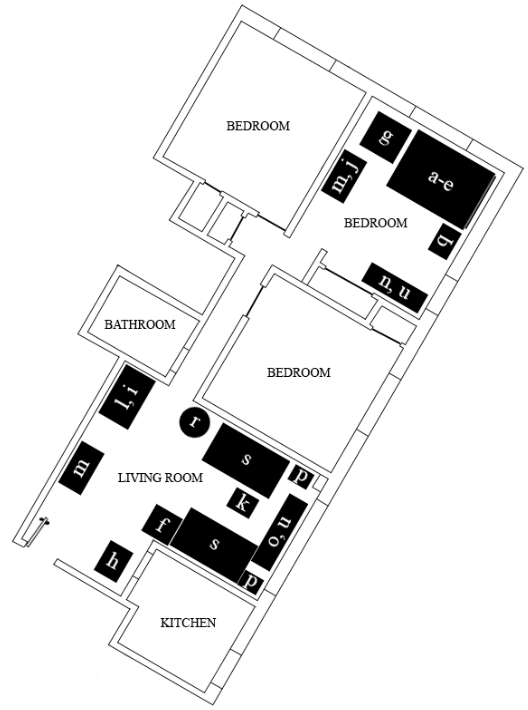



**Figure 1.4-2. Apartment K Fuel Layout**

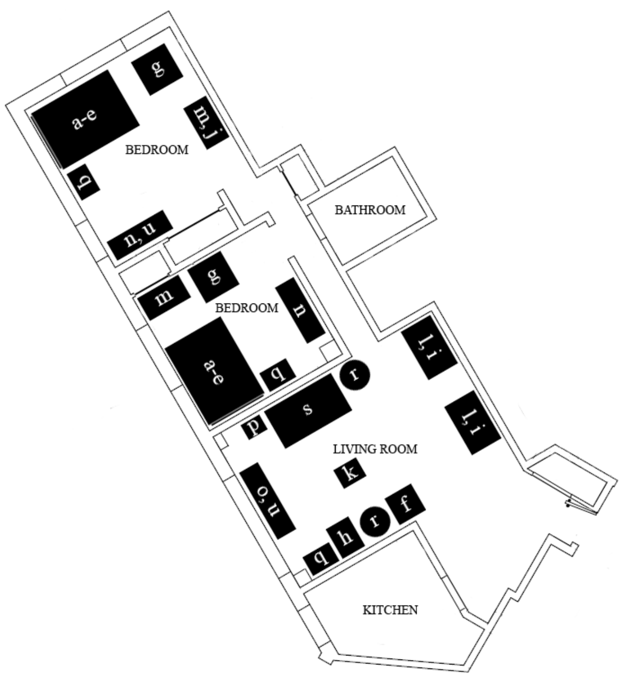



**Figure 1.4-3. Apartment G Fuel Layout**

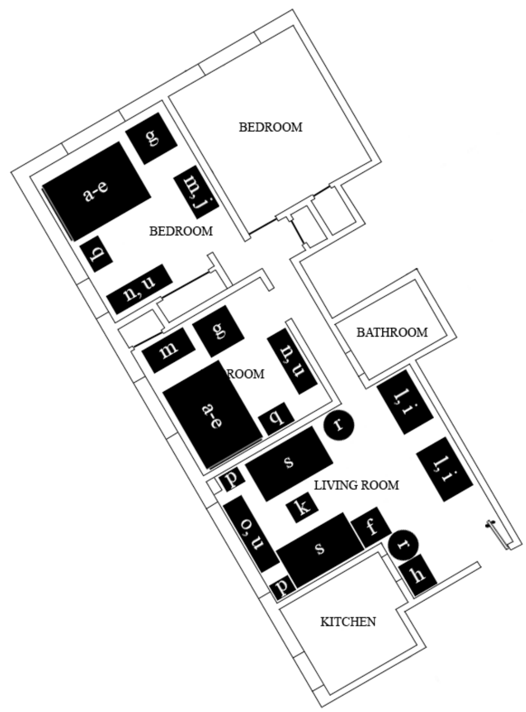



**Figure 1.4-4. Apartment K Fuel Layout**

### 1.4.1 Apartment A Photographs

Figure 1.4-5. View From Doorway

Figure 1.4-6. Living Room (View 1)

Figure 1.4-7. Living room (View 2)

Figure 1.4-8. View Down Hallway

Figure 1.4-9. Ignition Bedroom (View 1)

Figure 1.4-10. Ignition Bedroom (View 2)

## 1.4.2 Apartment E Photographs


**Figure 1.4-11. View From Doorway**


**Figure 1.4-12. Living Room (View 1)**


**Figure 1.4-13. Living Room (View 2)**


**Figure 1.4-14. Ignition Bedroom (View 1)**


**Figure 1.4-15. Ignition Bedroom (View 2)**


**Figure 1.4-16. Ignition Bedroom (View 3)**

### 1.4.3 Apartment G Photographs

**Figure 1.4-17. View From Doorway**

**Figure 1.4-18. Living Room (View 1)**

**Figure 1.4-19. Living Room (View 2)**

**Figure 1.4-20. Target Bedroom (View 1)**

**Figure 1.4-21. Target Bedroom (View 2)**

**Figure 1.4-22. Ignition Bedroom (View 1)**

**Figure 1.4-23. Ignition Bedroom (View 1)**

**Figure 1.4-24. Ignition Bedroom (View 3)**

### 1.4.4 Apartment K Photographs


**Figure 1.4-25. View From Doorway**


**Figure 1.4-26. Living Room (View 1)**


**Figure 1.4-27. Living Room (View 2)**


**Figure 1.4-28. Target Bedroom (View 1)**


**Figure 1.4-29. Target Bedroom (View 2)**


**Figure 1.4-30. Ignition Bedroom (View 1)**


**Figure 1.4-31. Ignition Bedroom (View 2)**


**Figure 1.4-32. Ignition Bedroom (View 3)**

## 1.5 Instrumentation

The measurements taken during the experiments included differential pressure, gas temperature, gas velocity, video recording and thermal imaging. Differential pressure transducers were located throughout the stairwells, 1.2 m (4 ft) above the floor on every landing (Figure 1.5-1). A copper tube was run from the transducers through the wall from the D or J Apartment into the stairwell to measure the pressure increase.

Gas temperature was measured with bare-bead, Chromel-Alumel (type K) thermocouples, with a 0.5 mm (0.02 in) nominal diameter. Thermocouple arrays were located in the ignition bedrooms, public hallways and stairwells (Figure 1.5-4). Each thermocouple location had an array of thermocouples with measurement locations of 0.03 m, 0.3 m, 0.6 m, 0.9 m, 1.2 m,1.5 m, 1.8 m and 2.1 m (1 in, 1 ft, 2 ft, 3 ft, 4 ft, 5 ft, 6 ft and 7 ft) below the ceiling (Figure 1.5-2).

Gas velocity was measured utilizing differential pressure transducers connected to bidirectional velocity probes. These probes were located in the fire apartment doorways, doorways into the stairwell as well as the stairwell doorways of the fire floors. There were three probes on the vertical centerline of each doorway located at 0.3 m (1 ft) from the top of the doorway, the center of the doorway and 0.3 m (1 ft) from the bottom of the doorway. Thermocouples were co-located with the bidirectional probes to complete the gas velocity measurement.

Video cameras and thermal imaging cameras were placed inside and outside the building to monitor both smoke and heat conditions throughout each experiment. As many as eight video camera views and two thermal imaging views were recorded during each test (Figure 1.5-3).

**Figure 1.5-1. Pressure Transducer**

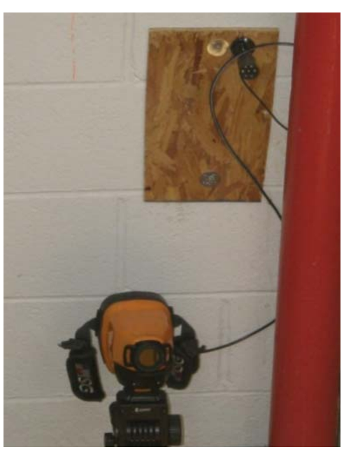


**Figure 1.5-3. Video and Thermal Imaging Cameras**

**Figure 1.5-2. Bidirectional Probes and Thermocouples**

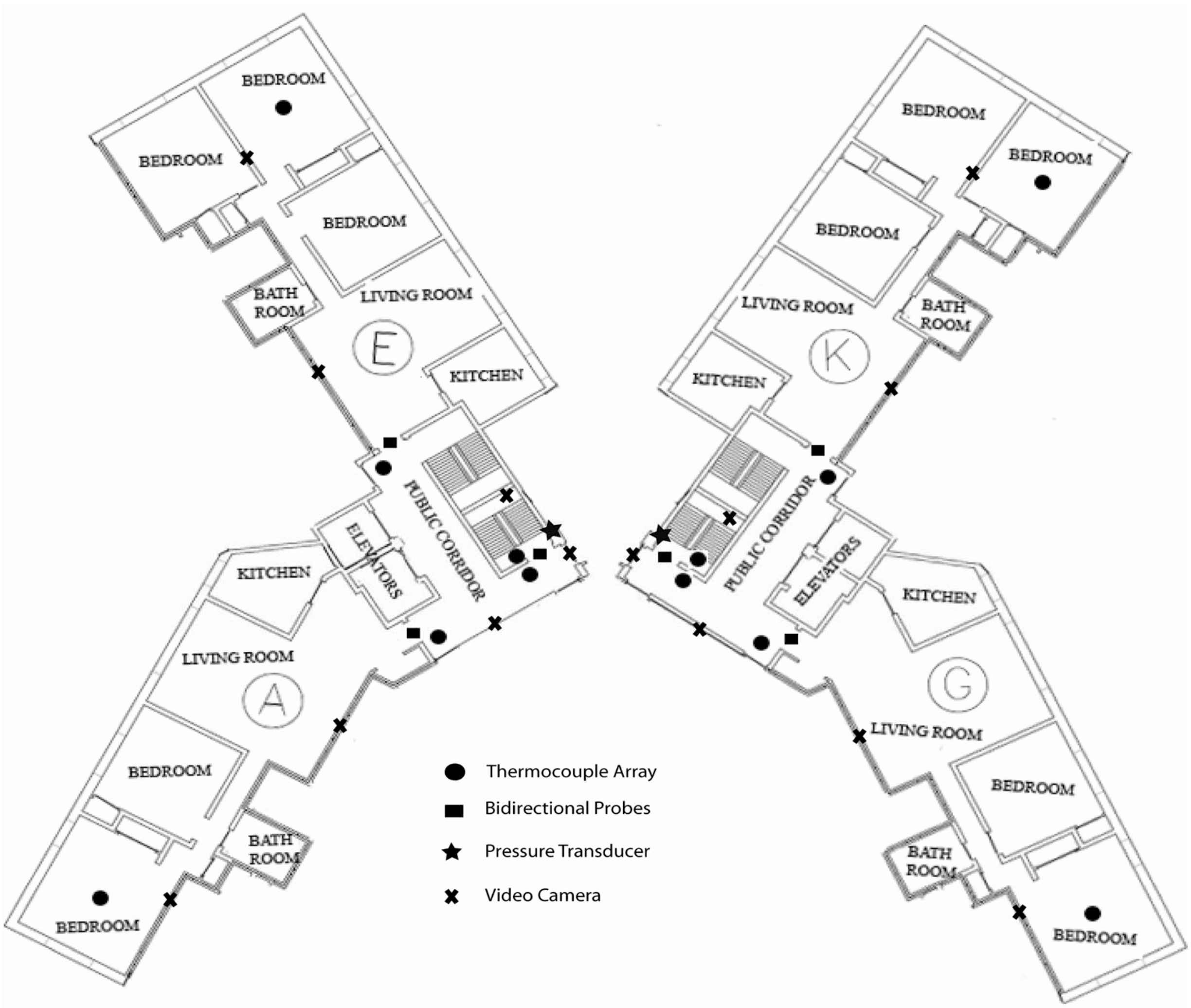



**Figure 1.5-4. Instrumentation Locations on Floors 3, 5 and 7**

## 1.6 Estimated Measurement Uncertainty

There are different components of uncertainty in the length, differential pressure and gas temperature data reported here. Uncertainties are grouped into two categories according to the method used to estimate them. Type A uncertainties are those which are evaluated by statistical methods, and Type B are those which are evaluated by other means [41]. Type B analysis of systematic uncertainties involves estimating the upper (+ a) and lower (- a) limits for the quantity in question such that the probability that the value would be in the interval (± a) is essentially 100 %. After estimating uncertainties by either Type A or B analysis, the uncertainties are combined in quadrature to yield the combined standard uncertainty. Multiplying the combined standard uncertainty by a coverage factor of two results in the expanded uncertainty which corresponds to a 95 % confidence interval ($2\sigma$).

Each length measurement was taken carefully. However due to some issues, such as obstructions and unleveled terrain there was a total expanded uncertainty of ± 6 % associated with the measurements.

Differential pressure reading uncertainty components were derived from pressure transducer instrument specifications and previous experience with pressure transducers. The transducers were factory calibrated and the zero and span of each was checked in the laboratory prior to the experiments yielding an accuracy of ±1% [42]. The total expanded uncertainty was estimated at 10 %.

The standard uncertainty in temperature of the thermocouple wire itself is ± 2.2 °C at 277 °C and increases to ± 9.5 °C at 871 °C as determined by the wire manufacturer [43]. The variation of the temperature in the environment surrounding the thermocouple is known to be much greater than that of the wire uncertainty [44, 45]. Small diameter thermocouples were used to limit the impact of radiative heating and cooling. The estimated total expanded uncertainty for temperature in these experiments is ±15 %.

Bi-directional probes and single thermocouples were used to measure the velocity. The bi-directional probes used similar pressure transducers as those used for the differential pressure measurements discussed above. Bare-bead Type K thermocouple are co-located with the probe. The estimated total expanded uncertainty for temperature in these experiments is ±15 %.

An error bar representative of the estimated uncertainty for each measurement is given on every data graph. The bar is applied near the peak measurement on the graph.

## 1.7 Positive Pressure Ventilation Fans

Several of the same model 0.7 m (27 in) positive pressure ventilation (PPV) fans were utilized for these experiments (Figure 1.7-1 and Figure 1.7-2). They were powered by a 9.0 hp gasoline engine and were used to ventilate and pressurize the stairwells of the structure during the experiments. Fans were positioned 1.8 m (6 ft) from the doorways that they were flowing into and tilted back 10 degrees from vertical. Fans were located at the front lobby doors, base of the stairwells on the first floor and two floors below the fire floor depending upon the experimental configuration.

Previous research has shown that PPV fans positioned correctly are able to create a pressure sufficient enough to keep products of combustion out of the stairwell by creating a higher pressure than the fire creates [39, 40]. These experiments follow the guidelines produced by the previous research to determine if the fans can be effective at keeping the combustion products out of the stairwell under wind driven conditions.

Figure 1.7-1. Front View of PPV Fans

Figure 1.7-2. Rear View of PPV Fans

## 1.8 Wind Control Blankets/Curtains

Two different Wind Control Devices (WCD) were used during these experiments. The first was a Wind Control Blanket (WCD). The WCD measured 3.0 m (10 ft) by 3.7 m (12 ft), was made of a silica fabric aluminized with a foil material and weighed approximately 14.0 kg (30.9 lb). It had a strap on each corner and one in the top center to secure it in the desired location. The WCD required a team of at least two fire fighters positioned above and a team of at least two fire fighters below the fire apartment to deploy and secure the blanket. One of the 3.7 m (12 ft) sides of the WCD was weighted with a chain to assist with deployment.

The second device was the Wind Control Curtain (WCD). The WCD measured 1.8 m (6 ft) by 2.4 m (8 ft), was made of a treated fiberglass material and weighed approximately 11.8 kg (26 lb). It was reinforced with metal rods and had a rope on each corner to secure it. The WCD could be deployed by a single fire fighter above the fire apartment and required an additional fire fighter below to secure the bottom of the curtain.

Figure 1.8-1. Wind Control Device Stowed

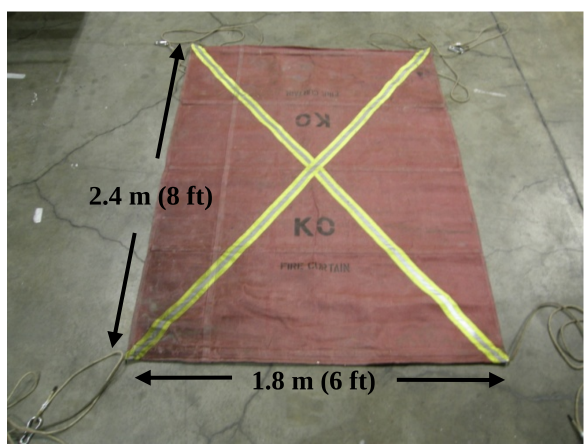



Figure 1.8-2. Wind Control Devi ce Open

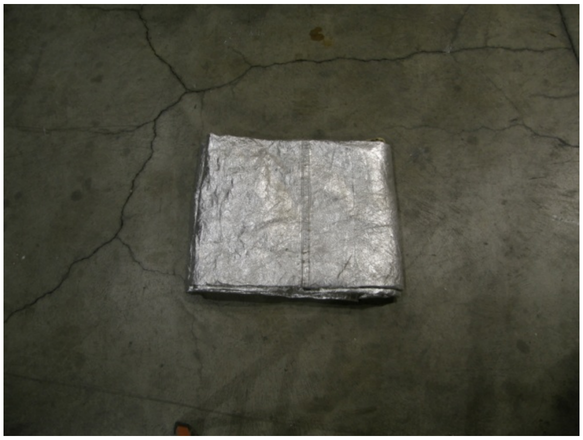


Figure 1.8-3.  Wind Control Device Stowed

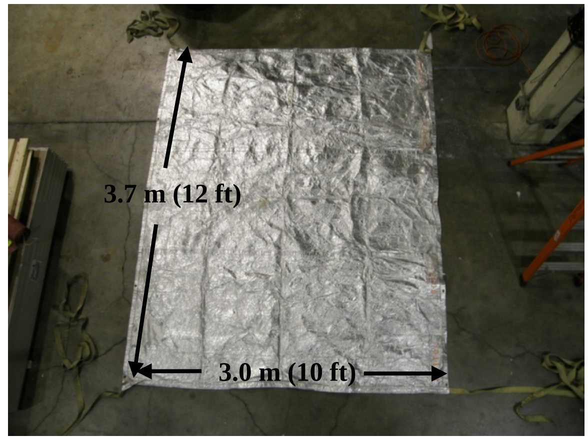



Figure 1.8-4.  Wind Control Device Open

Figure 1.8-5.  Wind Control Device Deployed


Figure 1.8-6.  Wind Control Device Deployed

## 1.9 Floor Below Water Application Nozzles

Two different types of Floor Below Nozzles (FBN) were utilized.  The first, referred to as FBN 1, was a bent pipe with the ability to attach a nozzle of choice.  This FBN was designed to be positioned straight out of the floor below the fire and by adjusting the distance out of the window the crew can direct the stream into the floor above (Figure 1.9-1).

The second type of FBN, referred to as FBN 2, was also of a bent pipe design.  The difference was that this nozzle was designed to hook onto the window sill of the floor above.  There were several prototypes of the FBN 2, varying the configuration to get the tip of the nozzle into the above apartment, but for the purposes of this analysis, they both will be grouped together (Figure 1.9-2).

Both types of FBN were able to accommodate any tip or water distribution device. Both a smooth bore and a fog tip were used for these experiments. The smooth bore was a 1 1/8 inch tip (Figure 1.9-1). The fog tip was considered any tip that created a broken water stream. Three versions of the fog tip that were used included a navy nozzle (Figure 1.9-3), sprinkler head type tip (Figure 1.9-4) and a common fog tip (Figure 1.9-7). Figure 1.9-5and Figure 1.9-6 show each of the FBN operating into the floor above.

**Figure 1.9-1. FBN 1 w/ a Smooth Bore Nozzle**

**Figure 1.9-2. One version of FBN 2**

**Figure 1.9-3. FBN 2 with a Fog Nozzle (Navy Nozzle)**

**Figure 1.9-4. FBN 2 with a Fog Nozzle (Sprinkler)**

**Figure 1.9-5. Floor Below Nozzle 1 Flowing**

**Figure 1.9-6. Floor Below Nozzle 2 Flowing**

**Figure 1.9-7. FBN 1 w/ Fog Tip**

**Figure 1.9-8. Another Version of FBN 2**

# 2 Experimental Procedure

Prior to the ignition of each experiment the MVU was placed into position and set to the appropriate speed. Three experiments 7G, 7G2 and 3G/K were an exception to this and utilized the natural wind. The computer acquisition system was started and data were collected from each instrument every second. Video cameras recording the experiment were also started at this time and monitored throughout the experiment. After the recording of background data, ignition was initiated remotely. Most of the experiments had the fire ignited in the corner bedroom of the apartment next to the bed. When the fire was initiated in the living room, the point of ignition was on the seat of one of the sofas.

The ignition source consisted of a cardboard book of 20 matches that was ignited by an electrically heated wire. The matchbook was placed near the bottom of an 8.5 L (9 qt) polypropylene waste container with a mass of 0.315 kg. The height of the waste container was 0.3 m (10.5 in) with interior dimensions at the top opening of 0.23 m (9.0 in) by 0.20 m (8.0 in). Approximately 0.3 kg of dry newspaper was added to the waste container. The majority of the newspaper was folded flat, and placed on edge along the sides of the waste container. Four sheets of newspaper were crumpled into "balls" approximately 100 mm in diameter and placed on top of the electric match in the center of the waste container. Heat release rate experiments were conducted for this fuel package under an oxygen consumption calorimeter at NIST. The peak heat release of the waste container and the newspaper was on the order of 30 to 35 kW for the two heat release rate experiments conducted. [1]

Every experiment began with all of the doors and windows closed with the exception of the door to the furnished bedrooms and the main entrance door from the public corridor to the fire apartment. After ignition, the fire was allowed to grow until it failed the windows in the room or became ventilation limited. The purpose of the experiments was to get a wind driven fire condition. Therefore when an apartment became ventilation limited because of lack of window failure additional doors were opened remotely such as the stairwell door to provide additional air for the fire to grow. In some cases, windows were manually vented to provide additional air flow.

Once wind driven conditions were achieved many different openings were made to simulate the operations of a fire department. These operations included opening the front lobby doors for access, entering the stairwell, opening the door from the stairwell to the fire floor, and opening the bulkhead door at the top of the stairwell. In addition to these operations each of the tools to be tested, PPV fans, Wind Control Devices and Floor Below Nozzles were deployed and evaluated.

The experiments were run until the fire burned down and smoke production was minimal. The experimental duration varied between 23 min and 53 min depending on the growth of the fire and the impact of the tactics. Detailed tables of the events are documented chronologically in the experimental timelines.

# 3 Results

During the series of wind driven fire experiments on Governors Island a large number of parameters which affect the flow of combustion products through a building and the ability to control the heat and velocity of those products of combustion were examined. In the data, the impacts of controlling doors, Positive Pressure Ventilation fans (PPV), Wind Control Devices (WCD), and Floor Below Nozzles (FBN) can be seen.

An overview of each experiment is provided with a list of experimental objectives. A figure in each experiment's results shows the pertinent locations such as doors and windows that change during the events of the experiment. A timeline shows all of the events that take place to accomplish the experimental objectives and the time at which they occur. The figures after the timelines show the locations for the cameras and instruments that are presented in the observation, temperature, pressure, velocity and discussion sections.

The temperature section has three graphs for each experiment. Each graph has lines and labels that indicate the changing events during the experiment. The first presents temperatures versus time throughout the fire apartment, public corridor and fire floor landing inside the stairwell at 2.1 m (7 ft) above the floor. This was the temperature approximately 0.3 m (1 ft) below the ceiling. The second graph presents the temperature at the same locations as the first graph but at the 1.2 m (4 ft) elevation above the floor. The third graph shows the temperatures at 1.2 m (4 ft) above the floor on the stairwell landings of floors 1, 2, 4, 6 and the top of the stairwell or at the bulkhead door.

The pressure section has a graph that shows the pressure versus time at 1.2 m (4 ft) above the landing on each floor. The graph has lines and labels that indicate the changing events during the experiment. The pressures in the stairwell are of the most interest when the PPV fans are being utilized to pressurize the stairwell to slow or stop the flow of fire gases into the stairwell.

The velocity section has a graph that shows the average doorway velocity versus time for the doors at the base of the stair, top of the stair, entrance to the stair from the fire floor and from the apartment to the public corridor. Velocity measurements were taken 0.3 m (1 ft) from the top of the door, 0.3 m (1 ft) from the bottom of the door and in the middle of the door on the centerline of the doorway. These measurements were averaged to provide the bulk flow through the doorway.

Detailed graphs are provided for each measurement point for each experiment in Appendix D – Detailed Graphs. The graphs include time histories of temperatures in multiple locations on the fire floor, temperatures throughout the stairwell, velocities of the fire floor, velocities in the stairwell and pressures in the stairwells. The legends indicate each instruments height above the floor in meters. The vertical axis of the temperature graphs provides the temperature in Centigrade on the left and Fahrenheit on the right. The vertical axis of the velocity graphs provides the velocity in meter per second of the left and miles per hour on the right. The horizontal axis provides the time in seconds. The experiment event timeline is given across the top of each graph. Time "zero" was when ignition took place.

## 3.1 Experiment 7G

The first experiment in the structure was located on the 7th floor in apartment 7G. Experiment 7G was ignited in the bedroom furthest from the open apartment door (Figure 3.1-1). This experiment was different from the other experiments, in that no external wind was being imposed to the structure and there was little to no natural wind. The events that took place during the experiment to accomplish the experimental objectives bulleted below are shown in Table 3.1-1.

Experimental Objectives

- Examine fire development with no mitigation and little/no wind
- Examine window failure times and conditions
- Examine building flows with different door opening configurations
- Utilize portable PPV fans to control smoke movement
- Utilize a MVU to control smoke movement

The results for the experiment are presented in the following sections: observations, temperature, pressure, velocity, and discussion. Figure 3.1-2 shows the camera names and locations used in the observation section and the instrumentation names and locations used in the temperature, pressure and velocity sections.

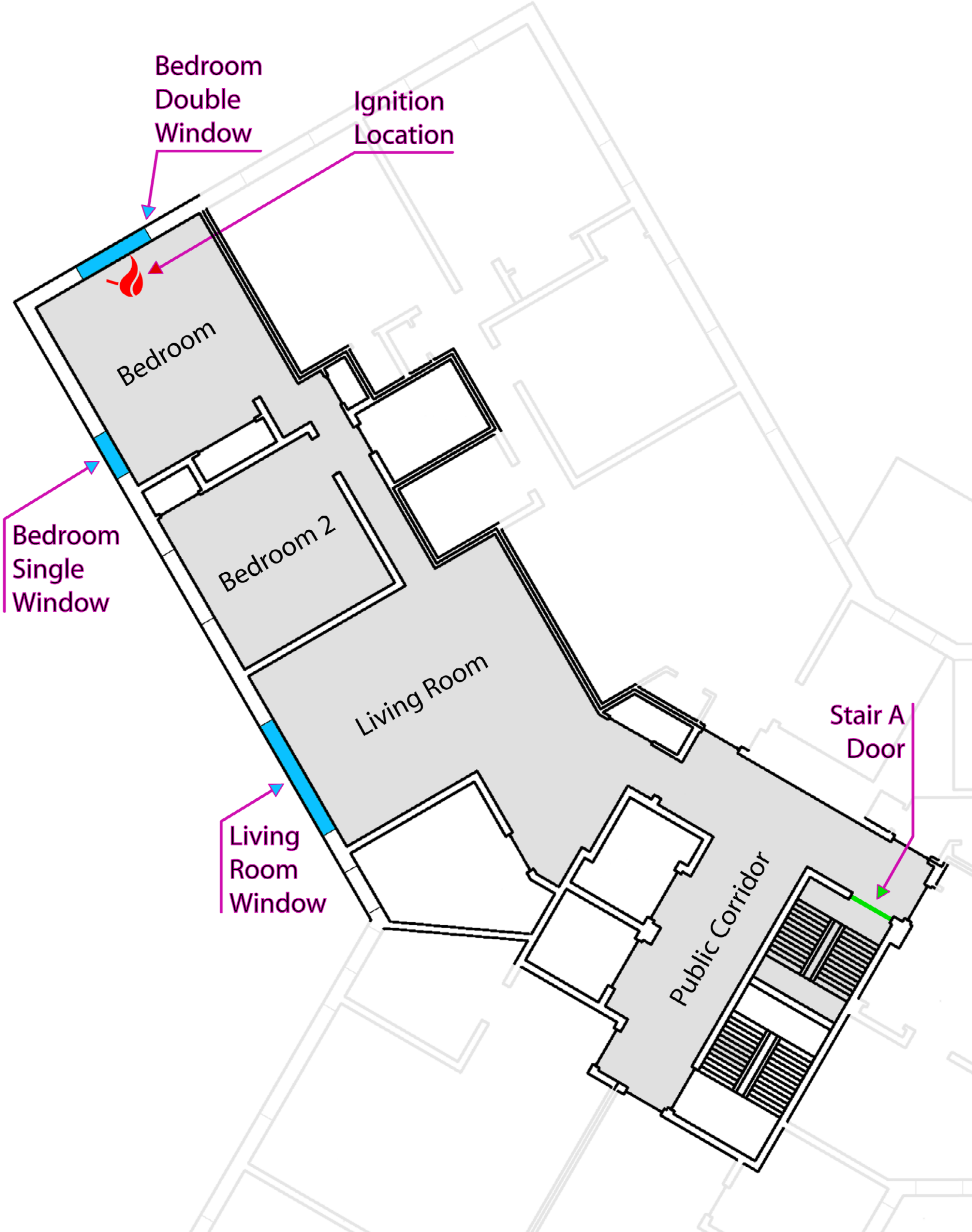



**Figure 3.1-1. 7th floor apartment G floor plan with locations pertinent to Experiment 7G**

**Table 3.1-1: Experiment 7G Timeline**

| Start (s) | End (s) | Event Location | Event Description |
|---|---|---|---|
| 0 | 0 | Bedroom | Ignition |
| 344 | 345 | Bedroom double | Bottom left pane failed |
| 365 | 372 | Front lobby | Doors opened |
| 402 | 405 | 1st floor stair A | Door opened |
| 438 | 439 | Bedroom double | Top left pane failed |
| 439 | 437 | Bedroom double | Top right pane failed |
| 847 | 849 | Bedroom double | Bottom right pane failed |
| 970 | 973 | Bedroom single | Top pane failed |
| 1195 | 1196 | Bedroom single | Bottom pane failed |
| 1224 | 1225 | 7th floor stair A | Door opened 0.08 m (3 in) |
| 1302 | 1307 | Bulkhead door | Opened |
| 1346 | 1352 | 7th floor stair A | Door opened |
| 1533 | 1542 | 1st floor stair A | 27 inch fan activated |
| 1569 | 1573 | Bulkhead door | Closed |
| 1715 | 1719 | 7th floor stair A | Door closed |
| 1839 | 1845 | 7th floor stair A | Door opened |
| 1847 | 1854 | Bulkhead Door | Opened & closed |
| 2060 | 2069 | 5th floor stair A | Door opened |
| 2060 | 2069 | 5th floor stair A | 27 inch fan activated |
| 2306 | 2313 | Front lobby | MVU started |
| 2401 | 2405 | 5th floor stair A | 27 inch fan deactivated |
| 2401 | 2405 | 5th floor stair A | Door closed |
| 2475 | 2487 | Front lobby | MVU stopped |
| 2600 | 2600 | Experiment completed | |

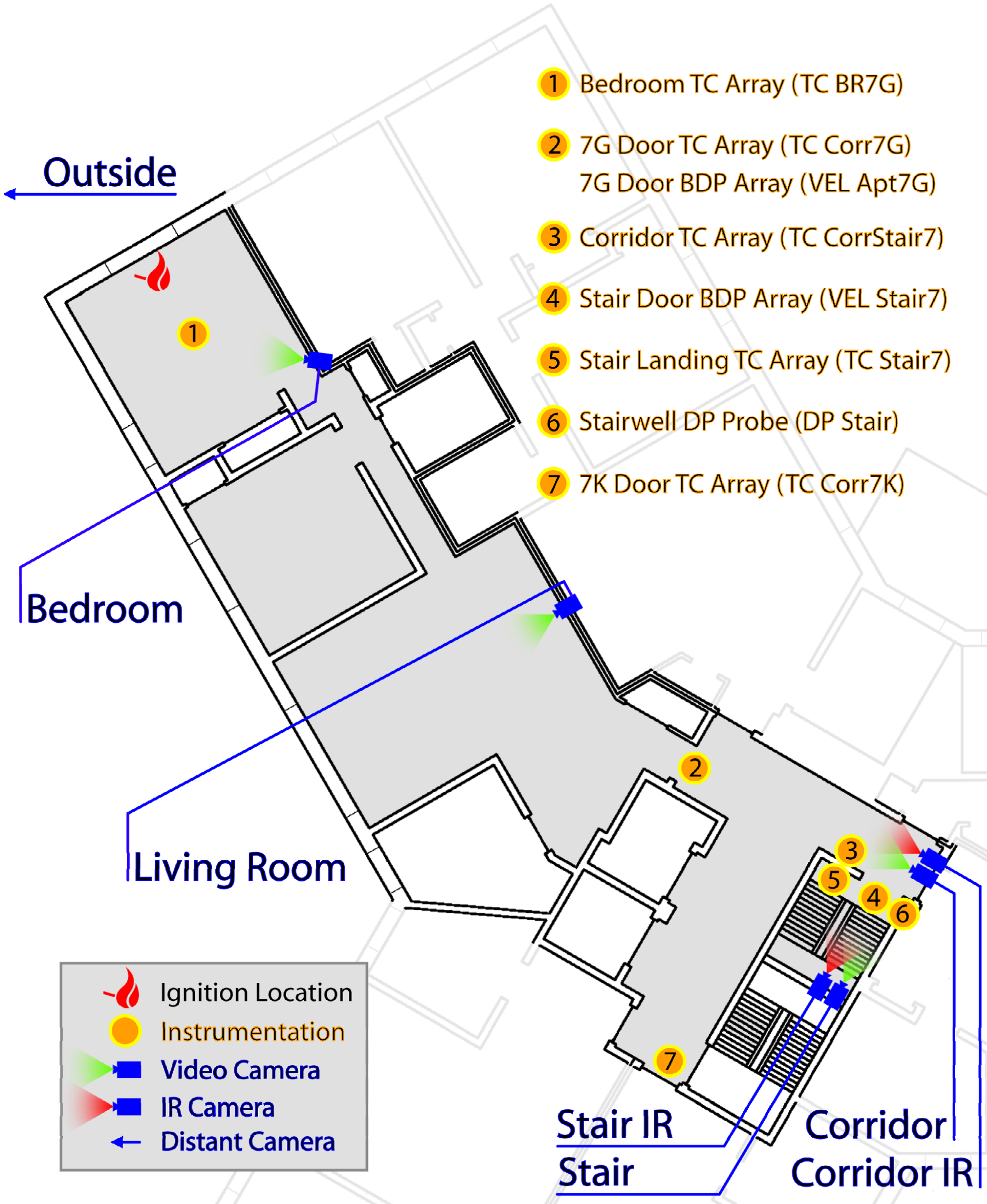



**Figure 3.1-2. Instrumentation and camera locations with labels.**

### 3.1.1 Observations

The observations are presented as a series of images captured from eight camera locations, six were video cameras and two were thermal imaging cameras. The camera positions inside the building are shown in Figure 3.1-2.

Figure 3.1-3 through Figure 3.1-16 present sets of eight images one from each camera position, at a given time, from the time of ignition to 44 min (2640 s) after ignition. Images were captured every 4 min and at times when events had taken place that demonstrate the experimental objectives. Each image view is labeled. The first view (BEDROOM) at the top left of each figure shows the bedroom with a view of the single window straight across, double window to the right and ignition trashcan at the foot of the bed. The top right view (LIVINGRM) was of the living room looking across to the windows. The corridor and corridor thermal imaging views (CORRIDOR and CORR IR) show the corridor leading up to the open apartment doorway. The next two views (STAIR and STAIR IR) show the stairwell with a visual and a thermal imaging camera from the floor below the fire looking up to the fire floor. The bottom left view (ROOF) shows the bulkhead door at the top of the stairwell and the bottom right view (OUTSIDE) shows an external view of the fire apartment.

Figure 3.1-3 shows the conditions at the time of ignition. At this point, the six video views are clear and unobstructed. However, the thermal images provided limited thermal contrast because the surfaces in the view are at nearly equal temperature.

The images in Figure 3.1-4 were captured 240 s (4 min) after ignition. The fire from the trash container spread to the bed. A smoke layer formed in the bedroom and descended to the floor level. Smoke spread through the living room and out into the corridor with a layer height of approximately 0.9 m (3 ft) above the floor. The corridor IR view showed heat leaving the top of the apartment doorway and entering the corridor. The stair views show little smoke in the stair and no heat entering the stair.

Figure 3.1-5 shows the images at 480 s (8 min) after ignition. The fire in the bedroom was ventilation limited and visibility was greatly reduced on the fire floor. Three of the four panes of glass in the bedroom double window had failed and smoke and heat was seeping around the gaps in the stairwell door. Smoke could also be seen leaking around the door at the roof level.

The images in Figure 3.1-6 were captured 720 s (12 min) after ignition. The fire in the bedroom was receiving oxygen from the failed double window and was beginning to increase in size. The smoke layer was still to the floor in the living room and the corridor. The light in the living room was reflecting off of the smoke but there was no fire in the living room. The corridor IR camera was saturated with heat but the door to the apartment was still visible. The smoke in the stairwell was moving up the stairwell toward the roof and the door to the stairwell was heating up.

Figure 3.1-7 shows the images at 960 s (16 min) after ignition. The single window in the bedroom had failed and the fire in the bedroom was continuing to grow on the bed. There was still zero visibility in the living room or corridor. The corridor IR view shows heat continuing to flow into the corridor. The conditions in the stairwell remained the same from the previous figure and no flames are visible coming from the bedroom windows.

Figure 3.1-8 shows the images at 1200 s (20 min) after ignition. The bed was fully involved in flames and the room was transitioning to flashover. Heat was continuing to flow into the corridor and visibility was still poor. There was increased smoke and heat leaking into the stairwell. Flames were burning out of the single bedroom window but only light smoke was visible from the double bedroom window.

The images in Figure 3.1-9 were captured 1440 s (24 min) after ignition. The door to the stairwell had been partially open for 120 s (2 min) and fully open for 90 s (1.5 min) and the bulkhead door had been open for 150 s (2.5 min). The bedroom had transitioned to flashover and was free burning. The amount of smoke in the living room and corridor was greatly reduced and visibility was improved as the fire was receiving plenty of air from the open windows and the stairwell. Increased heat was flowing into the corridor and cool air was entering the fire apartment through the bottom of the apartment doorway. The smoke and heat entering the stairwell was increased as the door was opened. The smoke was moving up through the stairwell and out of the open bulkhead doorway. The camera on the roof was completely obscured by smoke coming out of the stairwell. The flames had pulled into the bedroom and increased smoke was coming out of the double bedroom window.

The images in Figure 3.1-10 were captured 1530 s (25.5 min) after ignition. This time was just prior to PPV fan activation. The bedroom was still well involved in flames but the flames pulled back from burning the gases to the surfaces of the items in the room. Visibility in the living room and corridor remained the same as the previous figure but the same amount of heat and smoke was flowing into the corridor and stairwell. Visibility was returning to the roof area and the smoke flowing from the bedroom windows was decreased.

Figure 3.1-11 shows the images at 1650 s (27.5 min) after ignition. At this time the PPV fan at the base of the stair has been operating for 120 s (2 min) and the bulkhead door was closed for 90 s (1.5 min). The fan has increased the pressure in the stairwell stopping the flow of smoke and heat into the stairwell. Visibility was improved in the corridor but the fire is still forcing heat out of the fire apartment and into the corridor. Residual smoke in the stairwell was being forced out of the gaps around the roof door.

Figure 3.1-12 shows the images at 1680 s (28 min), 30 s after the previous figure. Conditions continued to improve in the stairwell as the smoke and heat flow we stopped with the use of the PPV fan.

Figure 3.1-13 shows the images at 1920 s (32 min) after ignition. At this time the PPV fan at the base of the stair has been operating for 380 s (6.3 min). The conditions continue to improve as the fire burns down. The heat from the fire is still able to exit the fire apartment but is not able to enter the stairwell. Figure 3.1-14 shows the images at 2160 s (36 min), after a second portable PPV fan was added at the 5$^{th}$ floor flowing into the stairwell. This added flow stops the flow of heat out of the fire apartment and reverses all flow back into the apartment. The stairwell and corridor now had complete visibility.

The final 2 figures, Figure 3.1-15 and Figure 3.1-16 show the conditions after the MVU was used outside of the structure blowing into the front doors. All of the smoke was cleared up to the bedroom and conditions were returned to near ambient. The fire had reduced to a pile of burning embers. The stair IR camera was knocked over by the flow from the MVU so that image was lost. There was no fire extension beyond the room of origin.


**Figure 3.1-3. Experiment 7G, ignition.**

Figure 3.1-4. Experiment 7G, 240s after ignition.

**Figure 3.1-5. Experiment 7G, 480s after ignition.**

**Figure 3.1-6. Experiment 7G, 720s after ignition.**

Figure 3.1-7. Experiment 7G, 960s after ignition.

Figure 3.1-8. Experiment 7G, 1200s after ignition.

Figure 3.1-9 Experiment 7G, 1440s after ignition.


**Figure 3.1-10 Experiment 7G, 1530s after ignition.**


**Figure 3.1-11 Experiment 7G, 1650s after ignition.**

**Figure 3.1-12 Experiment 7G, 1680s after ignition.**


**Figure 3.1-13 Experiment 7G, 1920s after ignition.**

Figure 3.1-14 Experiment 7G, 2160s after ignition.


**Figure 3.1-15 Experiment 7G, 2400s after ignition.**


**Figure 3.1-16 Experiment 7G, 2640s after ignition.**

### 3.1.2 Temperatures

Figure 3.1-17 through Figure 3.1-19 provide temperature data for five measurement locations on the fire floor at two elevations and throughout the height of the stairwell. The locations of the measurement points can be seen in Figure 3.1-2. The events that occurred during the experiment, as presented in Table 3.1-1, are listed on the top of the figures with lines at the time of the event. A time history for each thermocouple at each measurement location is located in Appendix D – Detailed Graphs.

Figure 3.1-17 shows the temperatures versus time at 2.1 m (7 ft) above the floor at 5 measurement locations, the bedroom, just outside the fire apartment in the corridor, just outside Apartment 7K in the corridor, just outside the A stairwell doorway, and just inside the A stairwell on the landing. The temperature in the bedroom rose to above 650 ºC (1202 ºF) before becoming ventilation limited and decreasing. At 345 s, the bottom left pane in the bedroom failed causing the temperature to decrease to approximately 400 ºC (752 ºF) as the fire responded to the availability of the cool outside air. Additional window panes failed and the fire grew and increased the temperature to above 800 ºC (1472 ºF). The fire became ventilation limited again and decreased back down to 650 ºC (1202 ºF) until the single window failed providing more oxygen. The temperature remained above 800 ºC (1472 ºF) for approximately 500 s. Once the fan was activated at the base of the stairwell with the 7$^{th}$ floor door open, the temperatures in the bedroom cooled to 600 ºC (1112 ºF). This decrease in temperature cannot be entirely attributed to the fan as the fire was beginning to burn down at the time of fan activation.

The three temperature measurement locations in the corridor behaved similarly which is consistent with the steady two layer environment that existed remote from the fire. Temperatures steadily increased as the fire in the bedroom increased. Temperatures increased to approximately 200 ºC (392 ºF) up until the fan was activated. The fan flow decreased the corridor temperatures to around 100 ºC (212 ºF) before the stairwell door was closed and the temperatures recovered. When the stairwell door was opened again and the fan flow could cool the temperatures decreased up until the end of the experiment.

The temperature in the stairwell remained near ambient until the stairwell door was opened. Once open the stairwell temperature at 2.1 m (7 ft) above the landing increased to 150 ºC (302 ºF). The fan activation decreased this temperature back down to ambient even with the door completely open on the fire floor. Closing and opening the door on the fire floor caused short duration temperature spikes as the pressure barrier created by the fan equalized the flow.

Figure 3.1-18 shows the temperatures at 1.2 m (4 ft) which would be more representative to where firefighters would be operating or occupants would be evacuating. The bedroom temperature increased to 400 ºC (752 ºF) before the fire became ventilation limited. The temperatures reacted to the failing windows and then the 1.2 m (4 ft) temperature began to track with the 2.1 m (7 ft) temperature after 1000 s which indicates flashover conditions in the bedroom. Beyond 1000 s the temperatures reacted the same as the previous figure.

The temperatures in the corridor steadily increased to approximately 150 ºC (302 ºF), until approximately 1350 s when the 7$^{th}$ floor stair door (bulkhead) was opened. At this time the temperature near the stairwell slightly decreased and the temperature near the fire apartment slightly increased. The activation of the fan decreased all of the corridor temperatures down to approximately 50 ºC (122 ºF).

Removing the fan flow by closing the door allowed temperatures to increase to around 100 ºC (212 ºF) before returning to ambient by opening the stair door.

The stairwell temperatures at 1.2 m on the landing of the fire floor remained below 100 ºC (212 ºF) with the door open and no mechanical ventilation but decreased to ambient with the fan operating. The addition of another fan or the MVU had no impact because the fire had burned down by the time of their implementation.

Figure 3.1-19 shows the temperatures 1.2 m (4 ft) above the landing on floors 1, 2, 4, 6 and at the bulkhead. As the fire was initially growing some hot fire gases leaked into the stairwell and increased the temperature at the top of the stairwell by 20 ºC (36 ºF). The cool air being pulled into the stairwell through stack effect was cooling the lower floors of the structure. When the 7th floor door was partially opened at 1225 s the temperature at the top of the stair increased again to 50 ºC (122 ºF) and cooled briefly as the bulkhead door was opened and then increased to a peak of 90 ºC (194 ºF). The fan activation decreased this temperature back down to 20 ºC (68 ºF) and kept it low for the remainder of the experiment.

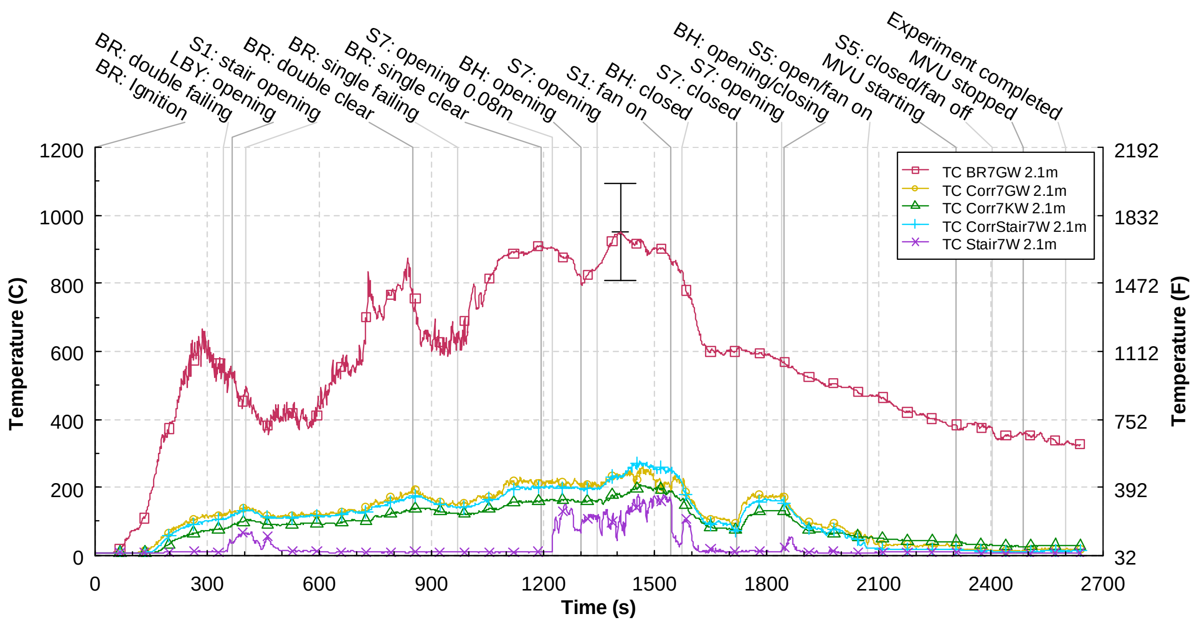



**Figure 3.1-17. 7G Temperature vs. time at 2.1 m above the floor**

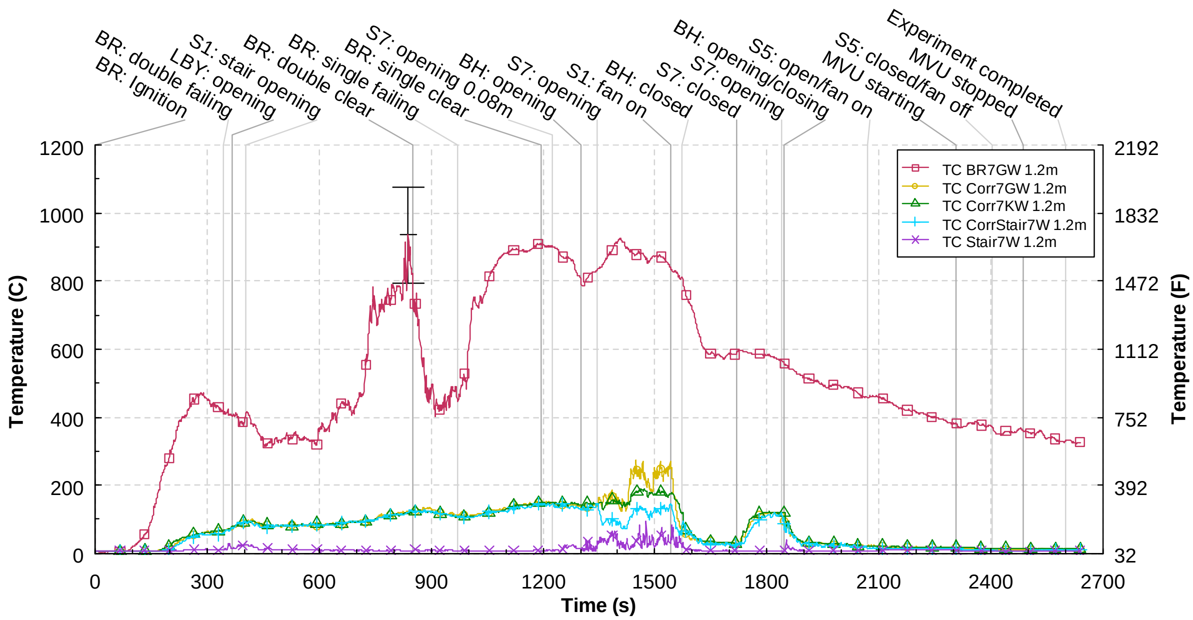



**Figure 3.1-18. 7G Temperature vs. time at 1.2 m above the floor**

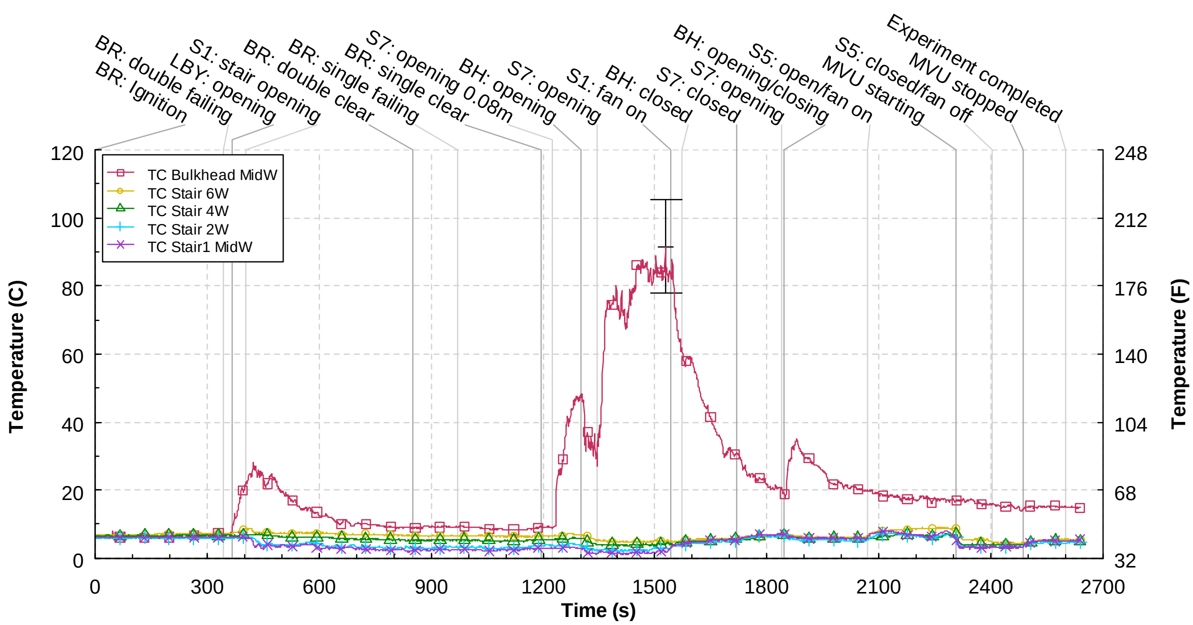



**Figure 3.1-19. 7G stairwell temperature vs. time**

### 3.1.3 Pressures

Average pressure measurements in the stairwell are shown in Figure 3.1-20. The differential pressure measurements were made at 1.2 m (4 ft) on the stairwell landing of every floor and referenced to an apartment on the same floor. With all of the doors to the stairwell closed the pressures remained below 5 Pa and only fluctuated slightly. Once the doors to the base of the stair were opened the pressures began to fluctuate but remained below 15 Pa. Opening the door at the top of the stairwell decreased pressures back to ambient conditions around 5 Pa. With the portable PPV fan operating at the base of the stair and the door to the 7th floor open the pressures averaged 15 Pa to 22 Pa. When the door to the 7th floor was closed the pressures increased to an average of 23 Pa to 30 Pa. After a second portable fan was added on the 5th floor and the 7th floor door was open the pressures averaged 20 Pa to 38 Pa. After the MVU was operating with the 7th floor door open the average pressures ranged from 55 Pa to 130 Pa.

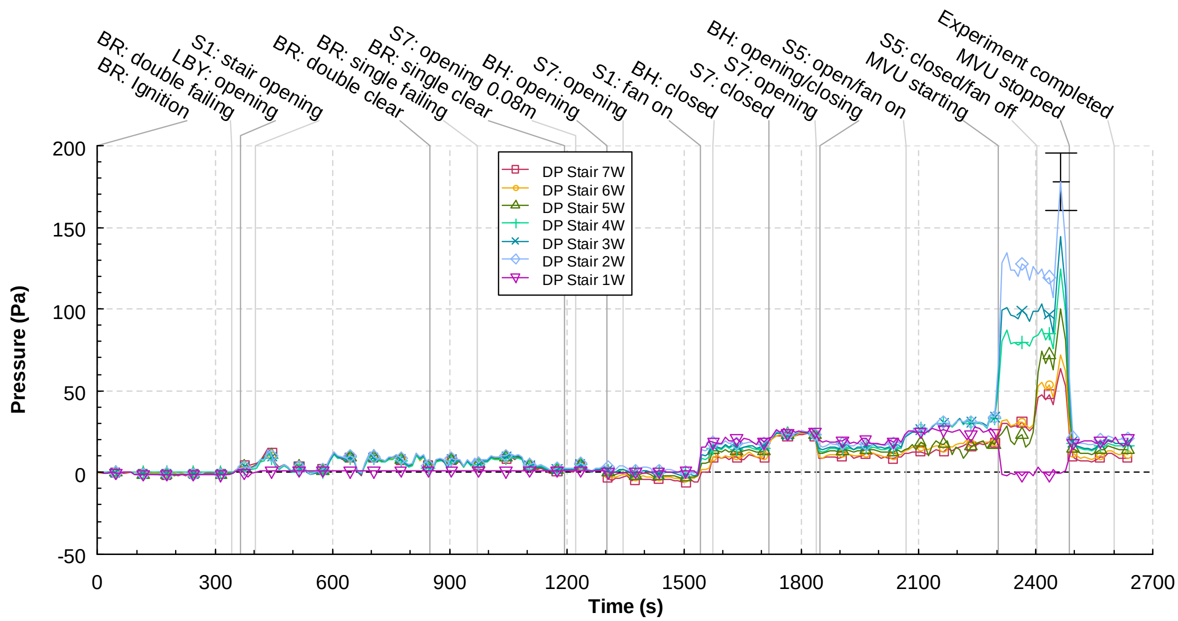



**Figure 3.1-20. 7G stairwell pressures vs. time**

### 3.1.4 Velocities

Average doorway velocities from 4 doors; the fire apartment door, the door from the fire floor to the stairwell, the door at the base of the stair and the door at the bulkhead, were recorded versus time and shown in Figure 3.1-21. The three bi-directional probes in each door were averaged to provide the bulk flow through the doors. A time history for each probe at each measurement location is located in Appendix D – Detailed Graphs.

The bulk flow out of the fire apartment steadily increased with the size of the fire. Prior to providing a vent, by opening the stair door, the bulk velocity was out of the apartment. Once the stair was opened and the bulkhead door was opened the bulk flow increased to a range of 1 m/s to 3 m/s (2 mph to 7 mph) out of the fire floor and a range of 2 m/s to 3 m/s (4 mph to 7 mph) out of the top of the stairwell. Once the PPV fan was activated these velocities converged at 0 m/s as the flow from the fan was equalizing the bulk flow from the fire. Once the MVU was activated there were large velocities through the structure and out through the fire apartment open windows. Flow in through the fire apartment door peaked at approximately 8 m/s (18 mph)

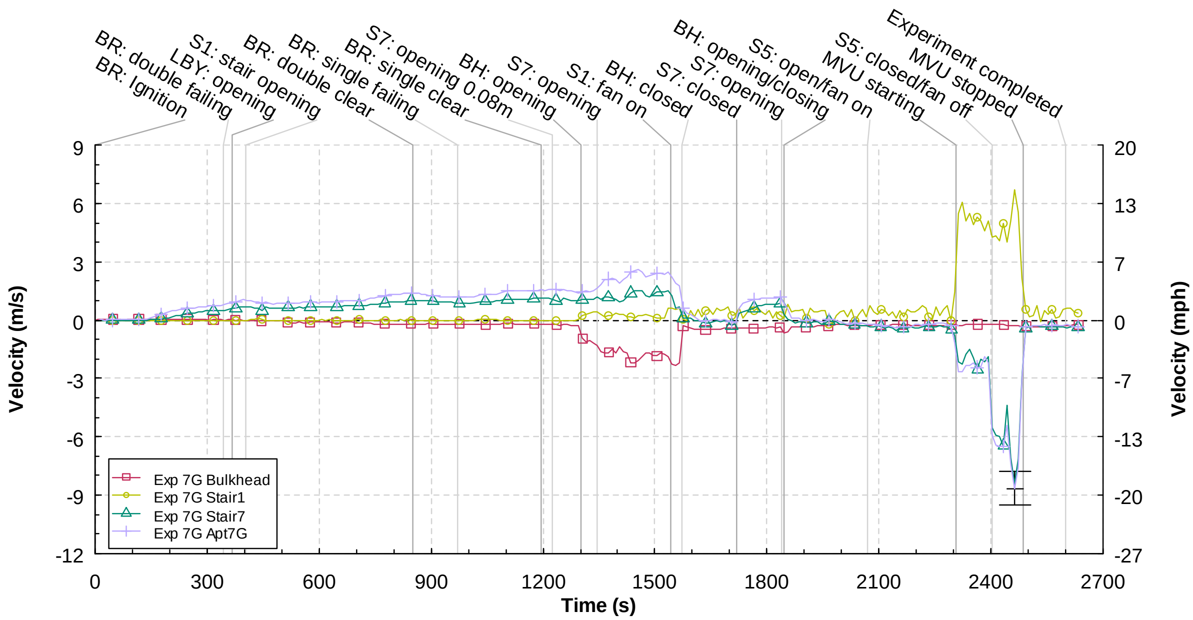



**Figure 3.1-21. 7G Velocities vs. time**

### 3.1.5 Discussion

This experiment served as a good baseline as to how the bedroom fires will behave without the influence of wind. Smoke quickly filled the fire apartment and corridor before becoming ventilation limited. Temperatures reached a threshold when the windows failed providing conditions for the fire to grow. Although high temperatures reached the corridor, the second bedroom and living room did not ignite and burn. The fire was contained to the room of origin.

The fire was deliberately ignited near the window to best allow for window failure. It took 345 s (5.75 min) to fail the double pane in the bottom left of the window closest to the flames. The internal pane of the double pane window failed much earlier but acted as an insulator protecting the outer pane from failure. The flame actually had to come into contact with the pane to fail it. It took 848 s (14.1 min) until all four panes of window failed. The air that was introduced through the first failed pane cooled the room causing the window to take longer to fail. The single window remote from the area of ignition took 972 s (16.2 min) to fail the top panes and 1196 s (19.9 min) to fail the bottom panes. There were flames coming out of the top portion of the window for more than 180 s (3 min) before the bottom panes fell out of the frame.

The opening of the stairwell door and the bulkhead door, although remote from the bedroom fire, caused the fire in the bedroom to intensify when open. As these vents were open the temperatures above 0.9 m (3 ft) rose by as much as 100 ºC (180 ºF) while the temperatures below 0.9 m (3 ft) decreased by as much as 75 ºC (135 ºF). Even with 3 open windows in the bedroom hot gases flowing into the stairwell intensified as the stairwell acted like a chimney.

The use of a single 0.7 m (27 in) portable fan was able to raise the pressures in the stairwell sufficiently to prevent smoke flow into the stairwell. Stairwell pressures achieved ranged from 15 Pa to 30 Pa with no doors open and with the door on the 7th floor open. The fan was implemented shortly after the fire reached its peak and maintained a smoke free stair for the duration of the experiment. Temperatures were cooled up to the fire apartment, and into the fire apartment once the fire burned down to a pile of rubble. The use of the MVU to ventilate was extremely effective at removing smoke and hot gases but was only used for overhaul type conditions.

## 3.2 Experiment 7G2

The second experiment in the structure was located in the same apartment as the first experiment, 7G. Experiment 7G2 was ignited in the middle bedroom in a trashcan at the base of the bed, and in the living room on the top of sofa that backed to the kitchen (Figure 3.2-1). The fire in the bedroom from the first experiment, Experiment 7G, did not extend beyond the room of origin so the apartment was cleared of smoke and experiment 7G2 was ignited. Both windows in the back bedroom failed in the previous experiment so they remained open during the duration of this experiment. This experiment also utilized natural ventilation conditions with no simulated wind and very little natural wind. The events that took place during the experiment to accomplish the experimental objectives below are shown in Table 3.2-1.

Experimental Objectives

- Create baseline data for fire conditions with no/little wind
- Examine window failure times and conditions
- Examine building flows with different door opening configurations
- Utilize portable PPV fans to control smoke movement

The results for the experiment are presented in the following sections: observations, temperature, pressure, velocity, and discussion. Figure 3.2-2 shows the camera names and locations used in the observation section and the instrumentation names and locations used in the temperature, pressure and velocity sections.

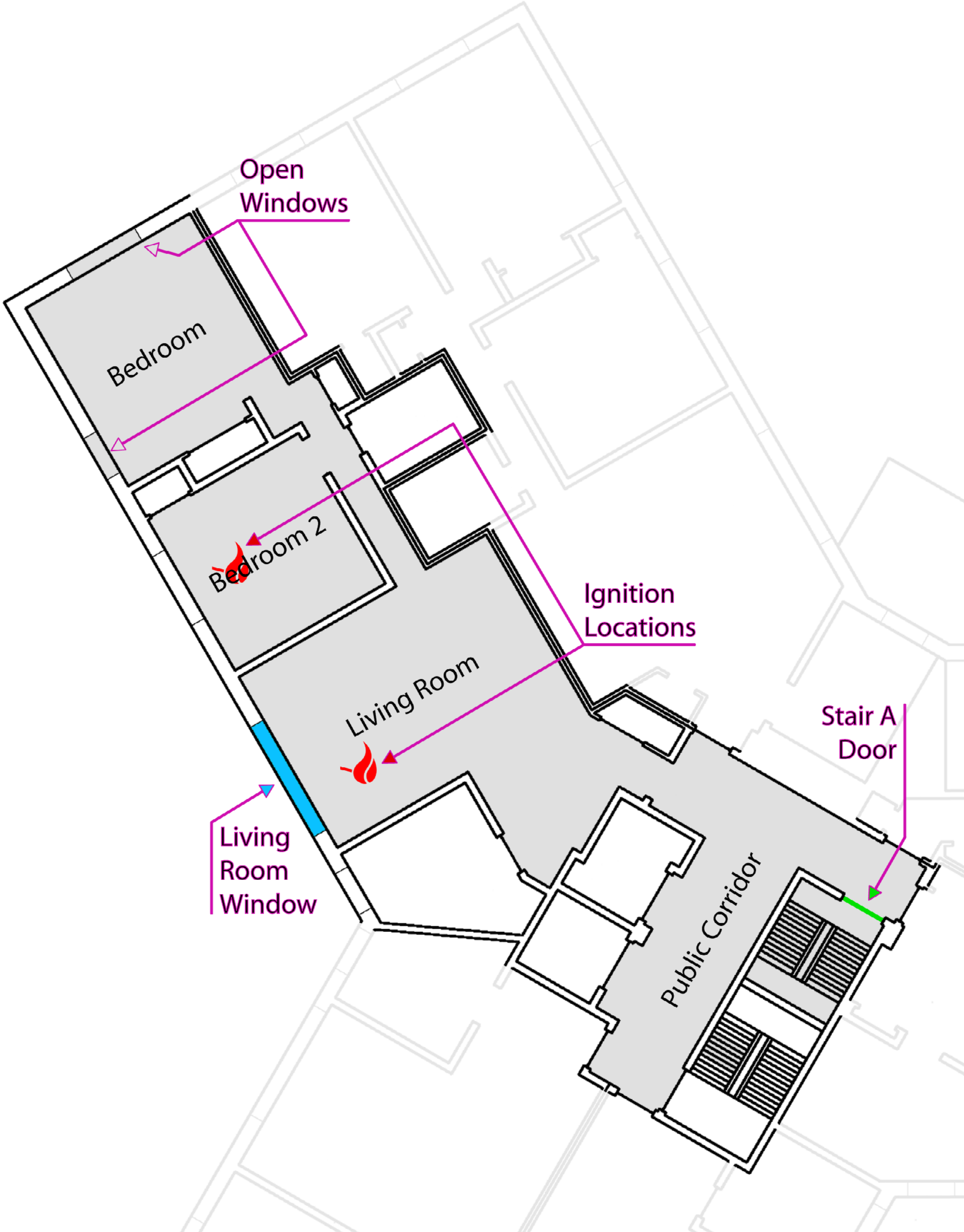



**Figure 3.2-1. 7th floor apartment G floor plan with locations pertinent to Experiment 7G2**

**Table 3.2-1: Experiment 7G2 Timeline**

| Start (s) | End (s) | Event Location | Event Description |
|---|---|---|---|
| 0 | 0 | Middle bedroom and living room | Ignition |
| 351 | 356 | Front lobby | Doors opened |
| 365 | 367 | 1st floor stair A | Door opened |
| 642 | 648 | 7th floor stair A | Door opened |
| 702 | 703 | Bedroom double | Top left pane failed |
| 755 | 762 | 1st floor stair A | Door closed |
| 766 | 767 | Bedroom double | Top right pane failed |
| 828 | 830 | 1st floor stair A | Door opened |
| 887 | 891 | Bulkhead door | Opened |
| 959 | 960 | Bedroom double | Bottom left pane failed |
| 982 | 999 | 1st floor stair A | 27 inch fan activated |
| 1075 | 1076 | Bulkhead door | Closed |
| 1353 | 1358 | 1st floor stair A | 27 inch fan deactivated |
| 1500 | 1502 | Bulkhead door | Opened |
| 1635 | 1643 | 1st floor stair A | 27 inch fan activated |
| 1766 | 1767 | Bulkhead door | Closed |
| | 1779 | Living room window | Bottom left pane failed |
| | 1794 | Living room window | Center pane failed |
| | 1805 | Living room window | Top left pane failed |
| | 1843 | Living room window | Top right pane failed |
| 1870 | 1886 | 5th floor stair A | Door opened |
| 1870 | 1886 | 5th floor stair A | 27 inch fan activated |
| 1874 | 1875 | Living room window | Completely failed |
| 1947 | 1966 | 7th floor stair A | Door closed |
| 2050 | 2054 | 7th floor stair A | Door opened |
| 2133 | 2136 | 7th floor stair A | Door opened 0.08 m (3 in) |
| 2229 | 2232 | 7th floor stair A | Door opened |
| 2351 | 2355 | 5th floor stair A | 27 inch fan deactivated |
| 2351 | 2355 | 5th floor stair A | Door closed |
| 2376 | 2376 | 1st floor stair A | 27 inch fan deactivated |
| 2554 | 2563 | 1st floor stair A | 27 inch fan activated |
| 2696 | 2699 | Bulkhead door | Opened |
| 2771 | 2774 | Bulkhead door | Closed |
| 3159 | 3159 | Experiment completed | |

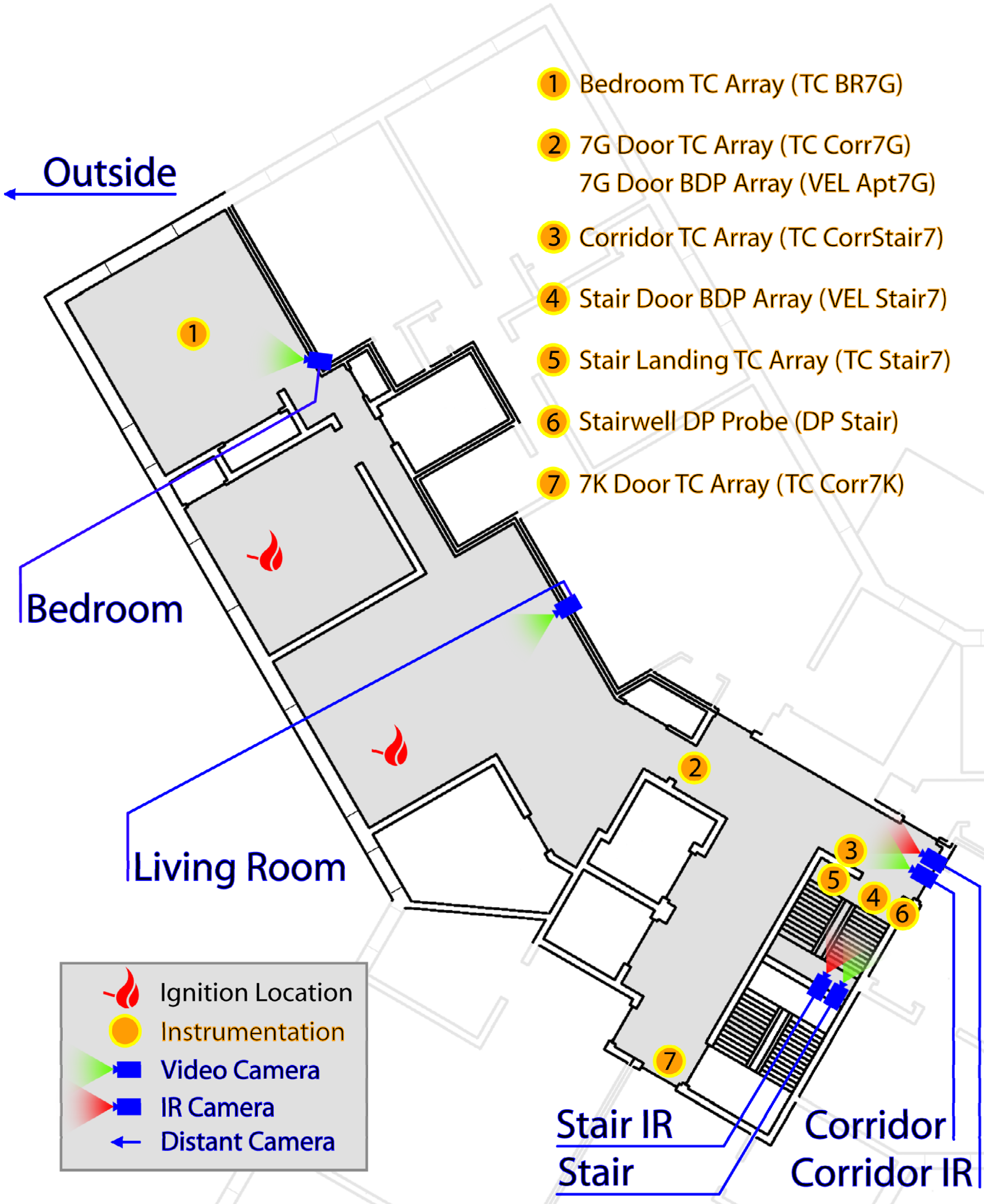



**Figure 3.2-2. Instrumentation and camera locations with labels.**

### 3.2.1 Observations

The observations are presented as a series of images captured from eight camera locations, six were video cameras and two were thermal imaging cameras. The camera positions inside the building are shown in Figure 3.2-2.

Figure 3.2-3 through Figure 3.2-21 present sets of eight images one from each camera position, at a given time, from the time of ignition to 48 min (2880 s) after ignition. Images were captured every 4 min and at times when events had taken place that demonstrate the experimental objectives. Each image view is labeled. The first view (BEDROOM) at the top left of each figure shows the bedroom which was burned in the 7G experiment, the bedroom furthest from the apartment entrance; the failed single window is straight across the view, and the failed double window is to the right of the view. The top right view (LIVINGRM) was of the living room looking across to the windows. The corridor and corridor thermal imaging views (CORRIDOR and CORR IR) show the corridor leading up to the open apartment doorway. The next two views (STAIR and STAIR IR) show the stairwell with a visual and a thermal imaging camera from the floor below the fire looking up to the fire floor. The bottom left view (ROOF) shows the bulkhead door at the top of the stairwell and the bottom right view (OUTSIDE) shows an external view of the fire apartment.

Figure 3.2-3 shows the conditions at the time of ignition. At this point, the six video views are clear and unobstructed. The thermal images show that there is some residual heat in the corridor and the stairway at the start of the experiment.

The images in Figure 3.2-4 were captured 240 s (4 min) after ignition. Fire involved half of the living room sofa where one of the two ignitions had occurred. A smoke layer had formed in the living room and was approximately 1.8m (6 ft) above the floor. The fire in the living room was directly visible from the corridor and corridor IR views.

Figure 3.2-5 shows the images at 480 s (8 min) after ignition. Visibility was low in the corridor and living room as the smoke layer had dropped to the floor in those areas. Smoke was visibly escaping the structure around the closed bulkhead door and through the failed windows in the bedroom furthest from the apartment entrance. Despite the smoke obscuration in the living room and corridor, visibility is still high in this bedroom due to the vented windows.

The images in Figure 3.2-6 were captured 720 s (12 min) after ignition. The 7$^{th}$ floor stairwell door had been opened and smoke began to descend the stairwell. A significant volume of smoke was leaking past the bulkhead door. The double window of the bedroom closest to the apartment entrance partially failed; flames and smoke were venting from the opening. Smoke density in the bedroom furthest from the apartment entrance was also significantly higher than four minutes prior.

Figure 3.2-7 shows the images at 960 s (16 min) after ignition. At this point the bulkhead door had been opened and visibility was reduced to zero in the outdoor roof view. Two additional panes in the window of the bedroom closest to the apartment entrance had failed and smoke as well as flames continued to vent from it. Limited visibility had returned to the floor level of the corridor. A clear heat layer is visible in the corridor IR and stair IR views as hot gasses pass through the ceiling of those areas.

Opening the bulkhead door lifted the smoke level in the stairwell but also increased the flow of hot gases through the corridor and into the stairwell.

Figure 3.2-8 shows the images at 1200 s (20 min) after ignition. At this point the window in the bedroom closest to the apartment entrance had completely failed and flames continued to vent from it. A portable PPV fan was activated and was ventilating the stairwell and then the bulkhead door was closed to pressurize the stairwell. The fan was operating for 200 s (3.4 min) and had improved conditions in the stairwell and corridor. The bulkhead door had been closed and little or no smoke is visibly leaking around it. Hot gas flow is not visible in either the corridor IR or the stair IR view. Visibility was high in all views except the living room, where visibility was limited.

The images in Figure 3.2-9 were captured 1440 s (24 min) after ignition. The condition of the window in the bedroom closest to the apartment entrance remained the same. The PPV fan was deactivated and the conditions in the stairwell worsened. Smoke began to fill the corridor again and hot gas flow was visible in the corridor IR at the corridor ceiling.

Figure 3.2-10 shows the images at 1680 s (28 min) after ignition. The bulkhead door had been opened and smoke flow through it was visible. The PPV fan was reactivated and conditions were improving in the stairwell and corridor. At this point the ignition sofa was fully involved and there was sufficient visibility in the living room to see it from the living room floor. Limited hot gas flow was visible in the corridor IR view because the camera switched to the extended mode (low sensitivity), and visibility was good in the corridor view.

Figure 3.2-11 shows the images at 1760 s (29 min and 20 s) after ignition. The fire in the living room was developing and increased heat was flowing into the corridor. Visibility in the lower layer of the corridor was still good as the fire was pulling fresh air from the stairwell.

The images in Figure 3.2-12 show the conditions at 1800 s (30 min) after ignition. The fire in the living room was becoming ventilation limited and the smoke layer had descended to the floor. One of the living room windows had failed and smoke and flames were flowing from the window. The bulkhead door had been shut for 36 s and the fan was establishing a pressure equilibrium to limit smoke and heat flow into the stairwell

Figure 3.2-13 shows the images at 1920 s (32 min) after ignition. The living room window had completely failed and flames were pushing out of it. The flames pulled to the air provided by the windows but the living room did not transition to flashover yet. The corridor IR view was saturated, which limits the contrast in the view, but heat was clearly visible in the stair IR view. Smoke was leaking around the closed bulkhead door.

Figure 3.2-14 shows the images at 1980 s (33 min) after ignition. The stair door to the 7$^{th}$ floor was closed to examine the impact of the PPV fan on smoke leakage around the door. The living room had transitioned to flashover and the fire was at its peak. The stairwell door was easily visible and there was no obvious heat flow around the door. The fan was forcing the residual smoke in the stairwell out around the cracks of the bulkhead door at the top of the stairwell.

Figure 3.2-15 shows the images at 2070 s (34 min and 30 s) after ignition. This was captured 15 s after the 7th floor stair door was reopened. The living room was still well involved in flames and the heat has stopped at the stairwell door by the fans pressure barrier. Smoke flow into the stairwell was greatly reduced and the visibility in the corridor was improved at the lower level.

Figure 3.2-16 shows the images at 2160 s (36 min) after ignition. Flames and smoke were continuing to vent from both the living room window and the window in the bedroom closest to the apartment entrance. A significant volume of smoke continued to leak around the closed bulkhead door. Visibility at the floor level of the corridor was significantly lowered as a result of smoke flow being stopped at the 7th floor stair A door, which was opened .08m (3 in).

Figure 3.2-17 shows the images at 2400 s (40 min) after ignition. At this point the 27 inch fans on the 5th and 1st floor stairwells were turned off, 43 s and 22 s prior, respectively. Significant hot gas flow is visible in the corridor IR and stair IR; smoke flow is visible in the cameras of those views. The increased heat flow into the corridor and stairwell caused both thermal imaging cameras to transition to extended mode. Smoke was descending down the stairwell making the stairwell door no longer visible.

Figure 3.2-18 shows the images at 2550 s (42 min and 30 s) after ignition. These were the conditions just prior to the fan at the first floor being started. The fire was burning down but the conditions in the stairwell were still poor. Figure 3.2-19 shows the images at 2580 s (43 min), 20 s after the fan at the first floor was reactivated. Smoke and heat flow into the stairwell were reduced.

Figure 3.2-20 shows the images at 2640 s (44 min) after ignition. Conditions were continuing to improve in the stairwell with the fan operating. The fire was burning down so the fan flow was clearing the corridor in addition to the stairwell. The smoke that was in the stair was being forced out around the closed bulkhead door.

Figure 3.2-21 shows the images at 2880 s (48 min) after ignition. At this point the fire had largely burned down and smoke had been cleared.


**Figure 3.2-3. Experiment 7G2, ignition.**


**Figure 3.2-4. Experiment 7G2, 240s after ignition.**

**Figure 3.2-5. Experiment 7G2, 480s after ignition.**

Figure 3.2-6. Experiment 7G2, 720s after ignition.

Figure 3.2-7. Experiment 7G2, 960s after ignition.

**Figure 3.2-8. Experiment 7G2, 1200s after ignition.**

Figure 3.2-9. Experiment 7G2, 1440s after ignition.

Figure 3.2-10. Experiment 7G2, 1680s after ignition.

**Figure 3.2-11. Experiment 7G2, 1760s after ignition.**

Figure 3.2-12. Experiment 7G2, 1800s after ignition.


**Figure 3.2-13. Experiment 7G2, 1920s after ignition.**


**Figure 3.2-14. Experiment 7G2, 1980s after ignition.**

Figure 3.2-15. Experiment 7G2, 2070s after ignition.

Figure 3.2-16. Experiment 7G2, 2160s after ignition.


Figure 3.2-17. Experiment 7G2, 2400s after ignition.

**Figure 3.2-18. Experiment 7G2, 2550s after ignition.**

Figure 3.2-19. Experiment 7G2, 2580s after ignition.

Figure 3.2-20. Experiment 7G2, 2640s after ignition.

Figure 3.2-21. Experiment 7G2, 2880s after ignition.

### 3.2.2 Temperatures

Figure 3.2-22 through Figure 3.2-26 provide temperature data for four measurement locations on the fire floor at two elevations and throughout the height of the stairwell. The locations of the measurement points can be seen in Figure 3.2-2. There was no temperature measurement location in the fire apartment for this experiment as it was damaged in the previous experiment in the same apartment. The events that occurred during the experiment are listed on the top of the figures with lines at the time of the event. A time history for each thermocouple at each measurement location is located in Appendix D – Detailed Graphs.

Figure 3.2-22 shows the temperatures versus time at 2.1 m (7 ft) above the floor at 4 measurement locations, just outside the fire apartment in the corridor, just outside Apartment 7K in the corridor, just outside the A stairwell doorway, and just inside the A stairwell on the landing. The three temperature measurement locations in the corridor behaved similarly which is consistent with the steady two layer environment that existed remote from the fire. Temperatures steadily increased as the fire in the bedroom and living room increased. Temperatures increased to approximately 250 ºC (482 ºF) up until the fan was activated. The fan flow decreased the corridor temperatures to below 100 ºC (212 ºF). After the fan was tuned off, and the fire in the living room began to escalate, the corridor temperatures increased to 200 ºC (392 ºF). When the bulkhead door was opened the corridor temperature peaked at 300 ºC (572 ºF). As the fire in the living room transitioned to flashover the temperature just outside the fire apartment reached 500 ºC (932 ºF). Closer to the stairwell when the fan was operating the corridor temperature did not exceed 300 ºC (572 ºF)

The temperature in the stairwell remained near ambient until the stairwell door was opened. Once open the stairwell temperature at 2.1 m (7 ft) above the landing increased to 150 ºC (302 ºF). The fan activation decreased this temperature back down to ambient even with the door completely open on the fire floor. The fan was turned off at 1359 s and the temperature quickly increased back to 150 ºC (302 ºF). There were a number of door opening and closings during the experiment and the stairwell temperature fluctuated between ambient and 150 ºC (302 ºF). Once the fire floor door was opened it took approximately 60 s to 90 s to establish the pressure barrier and return the temperature back to ambient. When the living room fire was near its peak the fans were turned off and the stairwell temperatures increased above 250 ºC (482 ºF). Activating the fan again at approximately 2560 s reduces the stairwell temperature from 250 ºC (482 ºF) to 50 ºC (122 ºF) in approximately 90 s.

Figure 3.2-23 shows the temperatures at 1.2 m (4 ft) which would be more representative of where firefighters would be operating or occupants would be evacuating. The temperatures in the corridor increased to approximately 120 ºC (248 ºF), and leveled off until the bulkhead door was opened. This event caused the temperature just outside the fire apartment to increase to 250 ºC (482 ºF). Turning the PPV fan on reduced this temperature quickly to below 100 ºC (212 ºF). Similar increases occurred again as the fan was tuned off and the bulkhead was opened. At approximately 1965 s the $7^{th}$ floor stair door was closed and the temperatures rapidly increased as the hot gas descended. Temperatures increased from 100 ºC (212 ºF) to above 400 ºC (752 ºF) in seconds. Reopening the door reduced temperatures just as quickly without raising the temperatures that much in the stairwell because of the flow of the fan. When the fans were turned off at 2376 s the temperatures throughout the fire floor increased from 200 ºC (360 ºF) to 400 ºC (720 ºF) in less than 10 s. Opening the bulkhead door while the fan was flowing, reducing pressurization and increasing ventilation, also caused temperatures to escalate quickly throughout the fire floor.

The stairwell temperatures at 1.2 m on the landing of the fire floor reached as high as 200 ºC (392 ºF) with the door open and no mechanical ventilation but decreased to near ambient with the fan operating. The addition of another fan at the 5th floor while the fire in the living room was at its peak decreased stairwell temperatures from 60 ºC (140 ºF) to 20 ºC (68 ºF).

Figure 3.2-24 shows the temperatures 1.2 m (4 ft) above the landing on floors 1, 2, 4, 6 and at the bulkhead door. Below the fire floor there was no significant change in temperature. Above the fire floor, at the bulkhead door, temperatures reached as high as 160 ºC (320 ºF) under normal ventilation conditions. Temperatures remained below 90 ºC (194 ºF) while fan were operating.

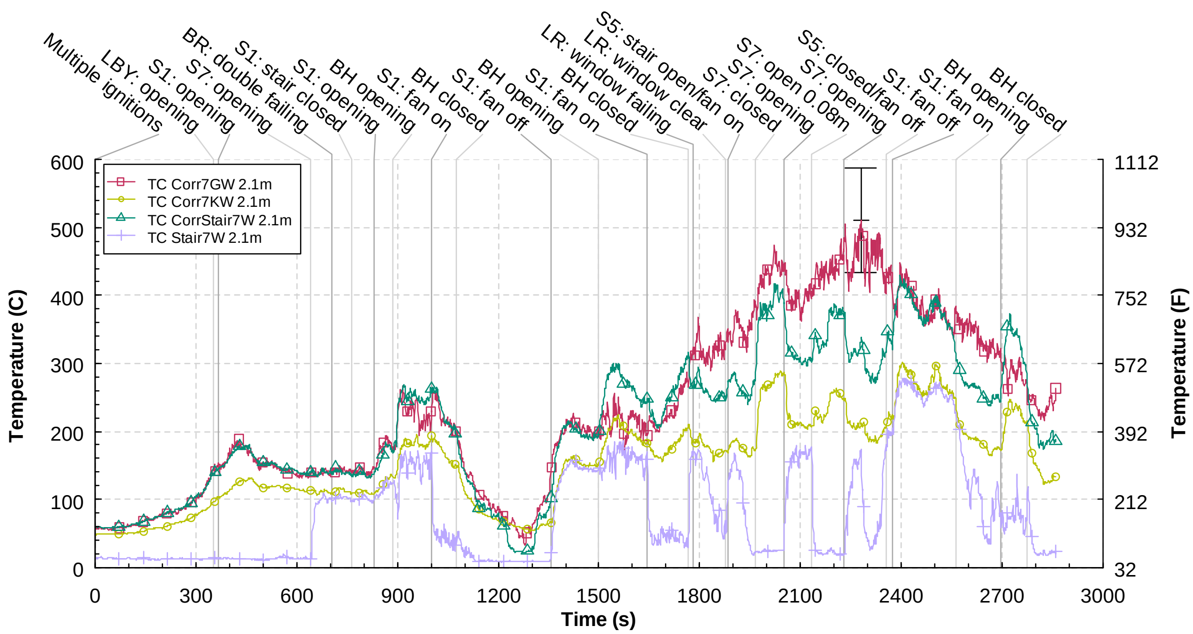



**Figure 3.2-22. 7G2 Temperature vs. time at 2.1 m above the floor**

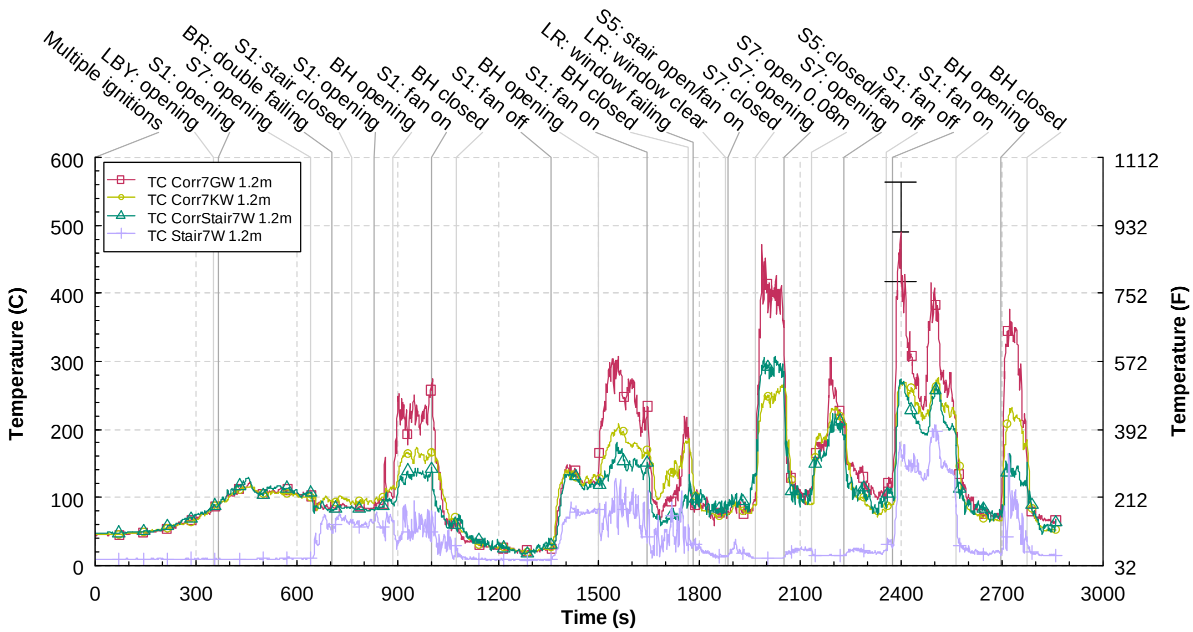



**Figure 3.2-23. 7G2 Temperature vs. time at 1.2 m above the floor**

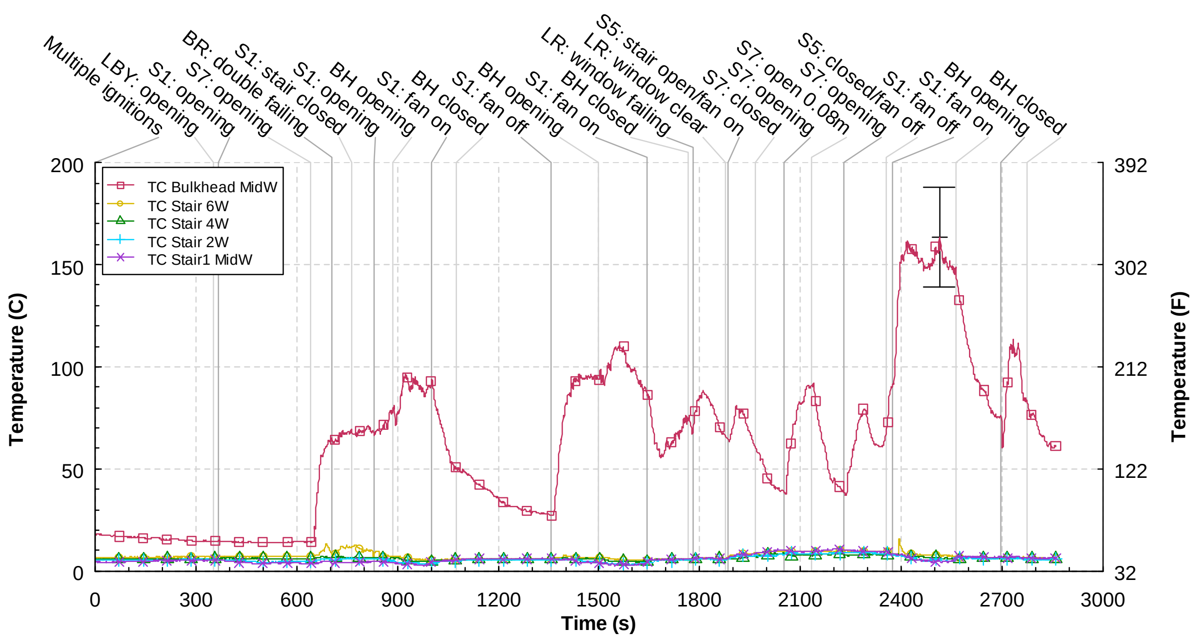



**Figure 3.2-24. 7G2 stairwell temperature vs. time**

## 3.2.3 Pressures

Average pressure measurements in the stairwell are shown in Figure 3.2-25. The differential pressure measurements were made at 1.2 m (4 ft) on the stairwell landing of every floor and referenced to an adjacent apartment on the same floor. With all of the doors to the stairwell closed the pressures remained below 5 Pa and only fluctuated slightly. Once the doors to the base of the stair were opened the pressures began to fluctuate but remained below 9 Pa.  Opening the door at the top of the stairwell decreased pressures back to ambient conditions around 5 Pa.  With the portable PPV fan operating at the base of the stair and the door to the 7th floor open the pressures averaged 13 Pa to 26 Pa.  After a second portable fan was added on the 5th floor and the 7th floor door was open the pressures ranged from approximately 15 Pa to 30 Pa.

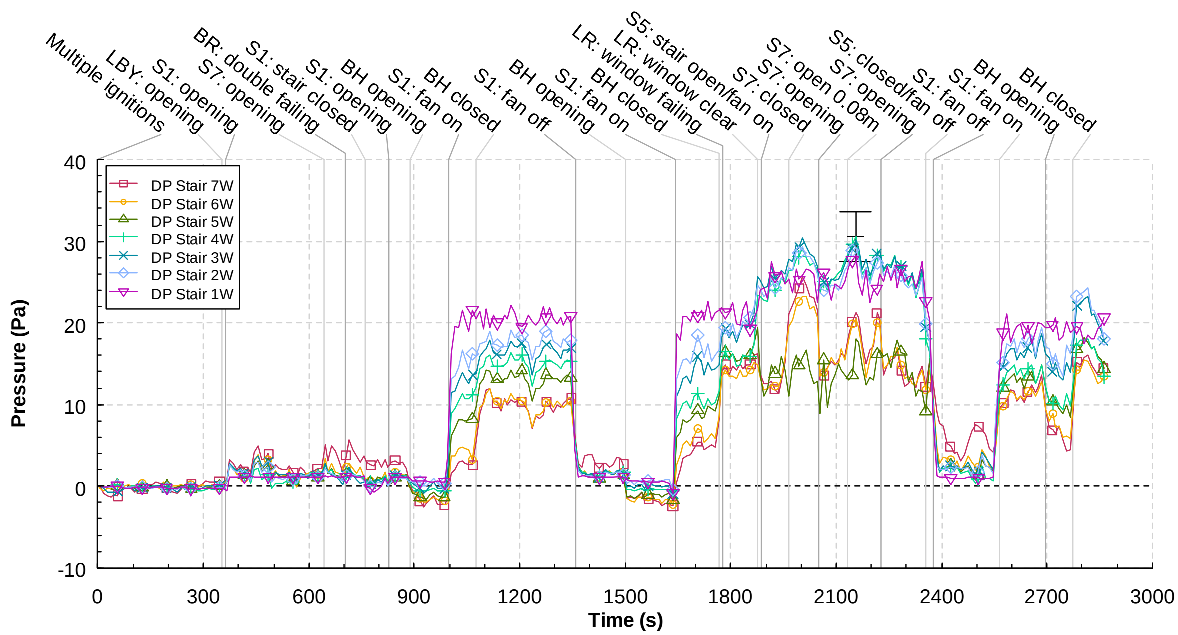



**Figure 3.2-25.  7G2 stairwell pressures vs. time**

### 3.2.4 Velocities

Average doorway velocities from 4 doors; the fire apartment door, the door from the fire floor to the stairwell, the door at the base of the stair and the door at the bulkhead,  were recorded versus time and shown in Figure 3.2-26.  The three bi-direction probes in each door were averaged to provide the bulk flow through the doors.  A time history for each probe at each measurement location is located in Appendix D – Detailed Graphs.

The bulk flow out of the fire apartment steadily increased with the size of the fire.  Prior to providing a vent, by opening the stair door, the bulk velocity was out of the apartment.  Once the stair was opened and the bulkhead door was opened the bulk flow increased to approximately 2 m/s (4 mph) out of the fire floor and 4 m/s (9 mph) out of the top of the stairwell.  Once the PPV fan was activated these velocities converged at 0 m/s as the flow from the fan was equalizing the bulk flow from the fire.

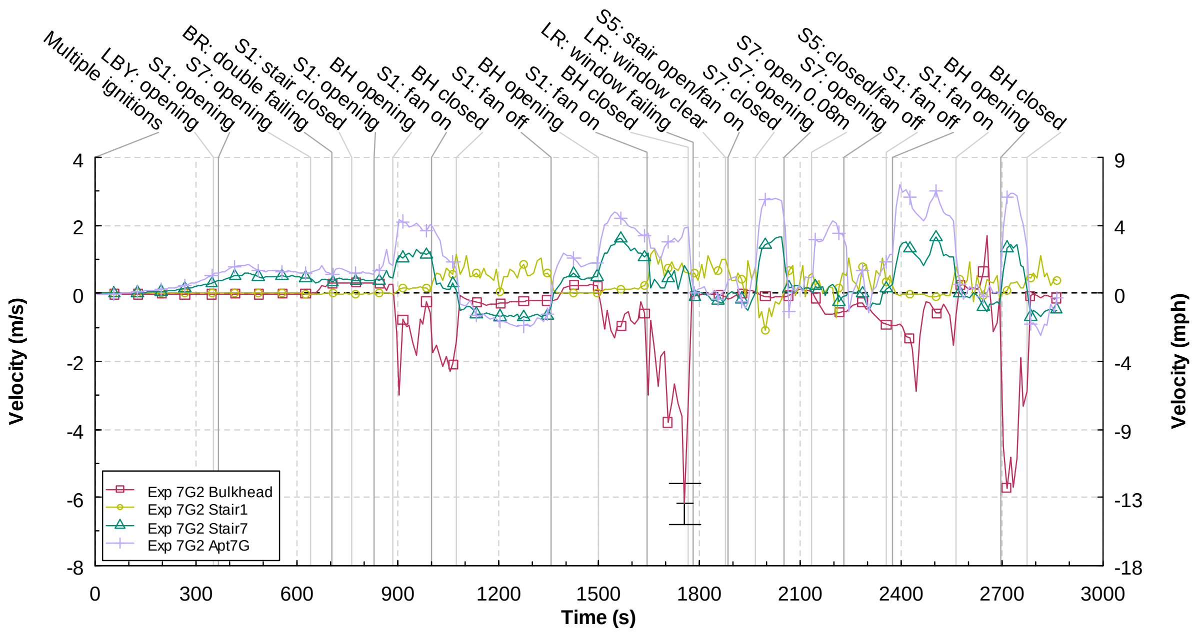



**Figure 3.2-26. 7G2 Velocities vs. time**

### 3.2.5 Discussion

This experiment served as a good baseline as to how a fire involving two rooms, a bedroom and living room, behaved without the influence of wind. The fire in the bedroom developed much faster than the living room, most likely because of the available oxygen from the open window in the bedroom from the previous experiment and the relatively small size. Smoke quickly filled the fire apartment and corridor before becoming ventilation limited. The fire in the living room reacted quicker to the changes in ventilation by opening the stairwell and bulkhead doors. The oxygen from the stairwell allowed the fire to grow and fail the windows, which drove the room to flashover.

It took 703 s (11.8 min) for the first dual pane window in the bedroom to fail, and 1053 s (17.6 min) for the entire window to fail. This time would have been longer or the window may not have failed if it was not for the open windows in the adjacent bedroom because the fire in the living room would have used up all of the oxygen coming from the stairwell. The living room window began to fail 1779 s (29.7 min) and completely failed at 1875 s (31.3 min). It appeared from the video that the flames had to touch the windows in order to fail them.

The opening of the stairwell door and the bulkhead door caused the fire in the bedroom and living room to intensify. The fire in this experiment was closer to the corridor and therefore reacted faster to the additional oxygen from the open door. As these vents were open the temperatures above 1.2 m (4 ft) rose by as much as 200 ºC (360 ºF). Even with 3 open windows in the rear bedroom, 2 open bedrooms in the other furnished bedroom and all of the living room windows open, hot gases flowing into the stairwell intensified as the stairwell acted like a chimney.

The single 0.7 m (27 in) portable fan was able to raise the pressures in the stairwell sufficiently to prevent smoke flow into the stairwell. When the stairwell door was opened there was typically a 60 s to 90 s period of turbulence until the pressures and flows reached steady state to stabilize the temperatures.

Stairwell pressures achieved ranged from 15 Pa to 30 Pa with no doors open and with the door on the 7th floor open. This was consistent with the first experiment. A fan was implemented multiple times and was able to create a smoke free stair or greatly reduce the flow of hot gases. The temperatures were greatly cooled up to the fire apartment on multiple occasions, and into the fire apartment once the fire burned down to a pile of rubble.

## 3.3 Experiment 7E

The third experiment in the structure was located on the 7th floor in apartment 7E, on the other half of the building from the first two experiments. Experiment 7E was ignited in the bedroom furthest from the open apartment door (Figure 3.3-1). This experiment was the first experiment with a simulated wind provided by the MVU. The simulated wind was imposed on the bedroom double window at a magnitude of approximately 9 m/s to 11 m/s (20 mph to 25 mph). Prior to the experiment the inner pane of the bedroom window was removed, leaving a single pane window. The events that took place during the experiment to accomplish the experimental objectives below are shown in Table 3.3-1.

Experimental Objectives

- Create wind driven fire conditions from a bedroom fire
- Examine window failure times and conditions
- Examine building flows with different door opening configurations
- Utilize portable PPV fans to control smoke movement

The results for the experiment are presented in the following sections: observations, temperature, pressure, velocity, and discussion. Figure 3.3-2 shows the camera names and locations used in the observation section and the instrumentation names and locations used in the temperature, pressure and velocity sections.

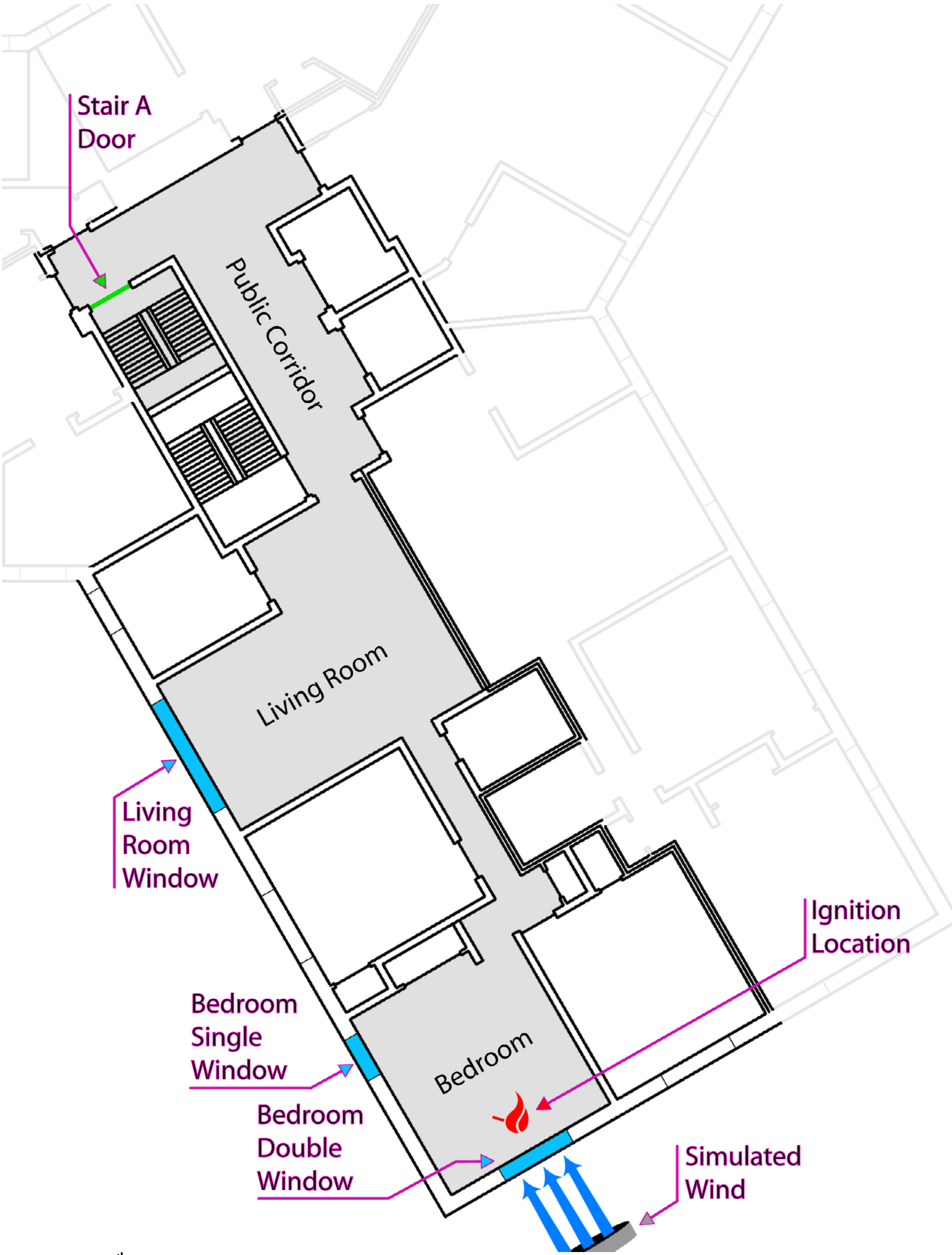



**Figure 3.3-1.  7th floor apartment E floor plan with locations pertinent to Experiment 7E**

**Table 3.3-1: Experiment 7E Timeline**

| Start (s) | End (s) | Event Location | Event Description |
|---|---|---|---|
| 0 | 0 | Bedroom | Ignition |
| 163 | 163 | Bedroom double | Bottom right pane failed |
| 163 | 165 | 7th floor stair A | Door opened 0.08 m (3 in) |
| 470 | 471 | Bedroom double | Top right pane failed |
| 475 | 484 | Front lobby | Doors opened |
| 492 | 497 | 1st floor stair A | Door opened |
| 534 | 535 | Bedroom double | Bottom left pane failed |
| 640 | 645 | Front lobby | 27 inch fan activated |
| 663 | 667 | 7th floor stair A | Door closed |
| 683 | 727 | Bedroom double | Top left pane failed |
| 705 | 710 | Bulkhead door | Opened |
| 782 | 807 | 1st floor stair A | 27 inch fan moved |
| 855 | 858 | 5th floor stair A | Door opened |
| 855 | 858 | 5th floor stair A | 27 inch fan activated |
| 1021 | 1033 | Bedroom double | Air flow adjusted |
| 1029 | 1032 | Bulkhead door | Closed |
| 1094 | 1107 | 7th floor stair A | Door opened 0.08 m (3 in) |
| 1222 | 1232 | 5th floor stair A | 27 inch fan deactivated |
| 1222 | 1232 | 5th floor stair A | Door closed |
| 1262 | 1266 | 7th floor stair A | Door opened 1/2 |
| 1310 | 1314 | Bulkhead door | Opened |
| 1379 | 1450 | Living room window | Failure |
| 1469 | 1471 | Bulkhead door | Closed |
| 1800 | | Experiment completed | |

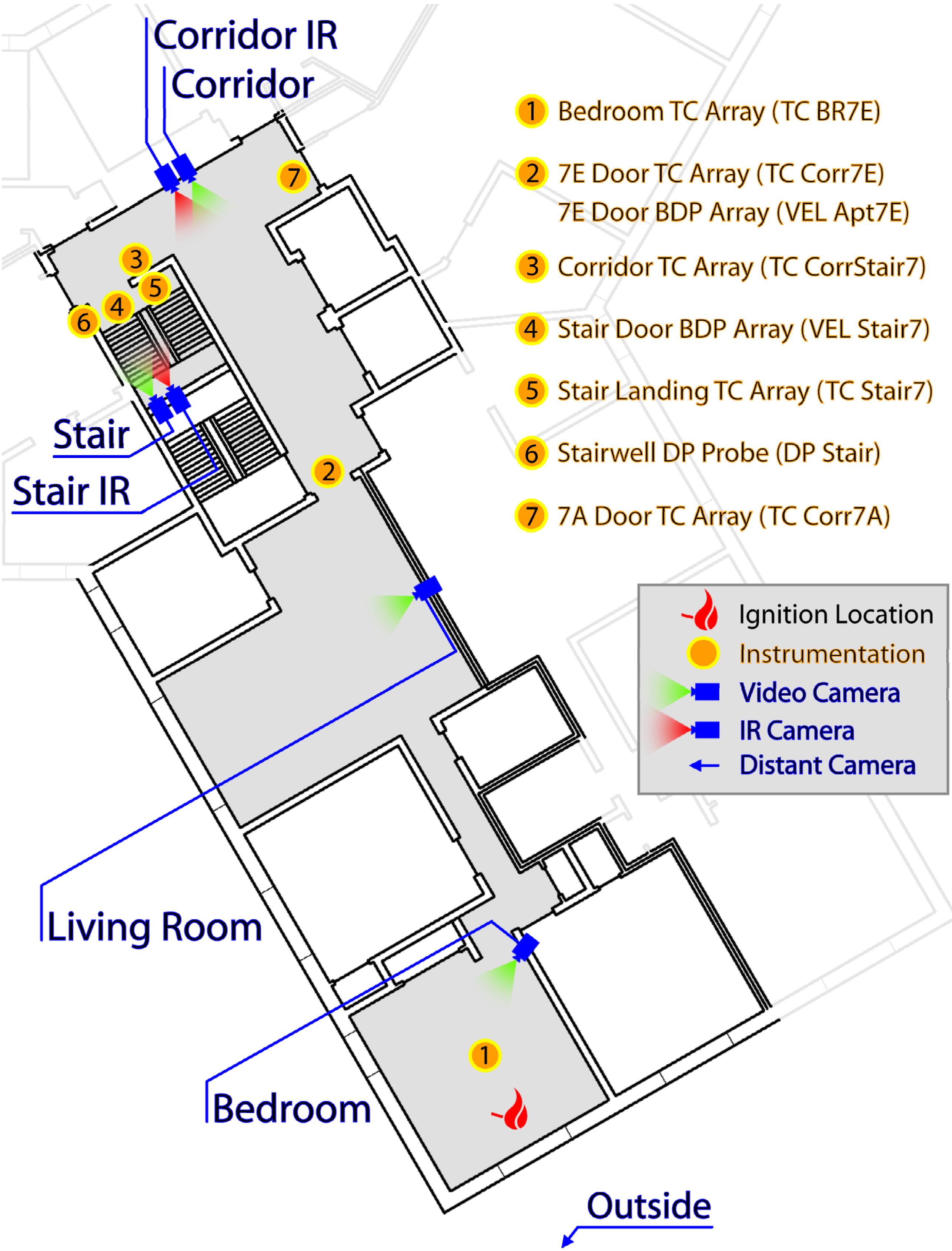



Figure 3.3-2. Instrumentation and camera locations with labels.

### 3.3.1 Observations

The observations are presented as a series of images captured from eight camera locations, six were video cameras and two were thermal imaging cameras. The camera positions inside the building are shown in Figure 3.3-2.

Figure 3.3-3 through Figure 3.3-17 present sets of eight images one from each camera position, at a given time, from the time of ignition to 28 min (1680 s) after ignition. Images were captured every 4 min and at times when events had taken place that demonstrate the experimental objectives. Each image view is labeled. The first view (BEDROOM) at the top left of each figure shows the bedroom of apartment 7E, the bedroom furthest from the apartment entrance with a view of the single window straight across, double window to the right and ignition trashcan at the foot of the bed. The top right view (LIVINGRM) was of the living room looking across to the windows. The corridor and corridor thermal imaging views (CORRIDOR and CORR IR) show the corridor leading up to the open apartment doorway. The next two views (STAIR and STAIR IR) show the stairwell with a visual and a thermal imaging camera from the floor below the fire looking up to the fire floor. The bottom left view (ROOF) shows the bulkhead door at the top of the stairwell and the bottom right view (OUTSIDE) shows an external view of the fire apartment.

Figure 3.3-3 shows the images at the time of ignition. At this point, the six video views were clear and unobstructed. However, the thermal images provided limited thermal contrast because the surfaces in the view are at nearly equal temperature.

Figure 3.3-4 shows the images at 240 s (4 min) after ignition. The fire from the trash container had spread onto the bed, and the smoke layer had descended to the floor of the ignition bedroom. The bedroom window had begun to fail approximately 75 s prior and the 7$^{th}$ floor stairwell A door was opened 0.08 m (3 in). The simulated wind forced the smoke throughout the public corridor and the stairwell, reducing visibility. Despite low visibility in the camera views for the corridor and stair, the temperature of the gas flow does not exceed 200ºC (392ºF) at the ceiling level. At this point, a small amount of smoke is visibly leaking around the bulkhead door.

Figure 3.3-5 shows the images at 480 s (8 min) after ignition. Visibility had not improved significantly from 240 s in the bedroom, living room, and corridor views. A second pane of the bedroom double failed 9 s prior and visibility in the stairwell view was slightly improved. Temperatures in the corridor visibly increased in the corridor IR.

Figure 3.3-6 shows the images at 720 s (12 min) after ignition. Flames involved the bedroom, reached the camera in the bedroom corner, and were visibly passing through the living room. The bulkhead door had been opened and the 7$^{th}$ floor stair A door had been closed, but visibility had not yet returned to the stairwell view. A portable PPV fan was activated but the impact on stairwell visibility can't be determined because the smoke that reached the camera deposited on the lens of the camera. Smoke was however exiting the open bulkhead door.

Figure 3.3-7 shows the images at 960 s (16 min) after ignition. At this point the bedroom double window had completely failed. Some visibility returned to the stairwell, and the stair IR view showed extreme contrast in temperature of the closed 7th floor stair A door and the rest of the stairwell.

Figure 3.3-8 shows the images at 1090 s (18 min and 10 s) after ignition. These were the conditions prior to opening the door from the 7th floor to the stairwell. The wind driven conditions are being held up at the door with no vent, hence no flow path. The door has heated up substantially as shown by the contrast in the thermal imaging view.

Figure 3.3-9 shows the images at 1170 s (19 min and 30 s) after ignition. Flames still involved most of the bedroom but none were visible elsewhere in the apartment. The door to the stairwell was opened 0.08 m (3 in) 70 s prior, and the two portable PPV fans were trying to keep the hot gases out of the stairwell and were not completely successful against the wind driven conditions.

Figure 3.3-10 shows the images at 1200 s (20 min) after ignition. The bulkhead door had been closed 170 s prior and the 7th floor stair A door had been reopened 0.08 m (3 in) 100 s prior. Smoke had not yet cleared the roof view.

Figure 3.3-11 shows the images at 1320 s (22 min) after ignition. The bulkhead door was opened approximately 10 s prior to this figure being captured. The wind forced the hot gases from the bedroom past the living room and ignited the sofa in the right side of the image. The wind driven fire gases were moving up the stairwell and through the bulkhead doorway.

Figure 3.3-12 shows the images at 1350 s (22 min and 30 s) after ignition, and 30 s after the sofa caught fire. The fire on the sofa had intensified and flames were beginning to be forced into the corridor. The fan was still operating on the first floor and the hot gases were traveling up the stairwell and not down to the floor below.

Figure 3.3-13 shows the images at 1380 s (23 min) after ignition. The fire in the bedroom was burning down but the fire in the living room was intensifying. The flames in the corridor reached the stairwell doorway and the view in the stairwell was beginning to clear up. The stair IR view shows high levels of heat coming out of the fire floor. The corridor IR camera view was saturated with heat and was unusable.

Figure 3.3-14 shows the images at 1440 s (24 min) after ignition. Flames were pushing out of the living room window which had failed. The bulkhead and 7th floor stair A doors had been opened prior to the window failing. The flames now involved all of the living room and corridor. Even though the living room window vented, flames were still traveling to the stairwell. Visibility was high in the stairwell view, as most of the heat and smoke traveled up the stairs.

Figure 3.3-15 shows the images at 1480 s (24 min and 40 s) after ignition. The living room was still fully involved, with flames being forced out of the window and extending above the roof line. The corridor camera still showed a view although it was on the brink of failure. Flames were no longer visible in the stairwell view but the thermal imaging view showed heat continuing to enter the stairwell.

Figure 3.3-16 shows the images at 1560 s (26 min) after ignition. The fire in the living room was still venting out of the windows from top to bottom and the internal camera became covered with soot, eliminating that view. The camera in the corridor finally failed and that thermal view was still not usable. The bulkhead door had been closed for 90 s and the pressure from the fan was maintaining visibility in the stair and limiting the heat flow.

Figure 3.3-17 shows the images at 1680 s (28 min) after ignition. Limited combustion was occurring in the bedroom where ignition occurred and there was zero visibility in the living room view, however flames were still pushing from the living room window. The fan was continuing to improve conditions in the stairwell.

**Figure 3.3-3. Experiment 7E, ignition.**

**Figure 3.3-4. Experiment 7E, 240s after ignition.**

**Figure 3.3-5. Experiment 7E, 480s after ignition.**

**Figure 3.3-6. Experiment 7E, 720s after ignition.**

**Figure 3.3-7. Experiment 7E, 960s after ignition.**

Figure 3.3-8. Experiment 7E, 1090s after ignition.

Figure 3.3-9. Experiment 7E, 1170s after ignition.

Figure 3.3-10. Experiment 7E, 1200s after ignition.


**Figure 3.3-11. Experiment 7E, 1320s after ignition.**


**Figure 3.3-12. Experiment 7E, 1350s after ignition.**

**Figure 3.3-13. Experiment 7E, 1380s after ignition.**

Figure 3.3-14. Experiment 7E, 1440s after ignition.

Figure 3.3-15. Experiment 7E, 1480s after ignition.

**Figure 3.3-16. Experiment 7E, 1560s after ignition.**

Figure 3.3-17. Experiment 7E, 1680s after ignition.

### 3.3.2 Temperatures

Figure 3.3-18 through Figure 3.3-20 provide temperature data for five measurement locations on the fire floor at two elevations and throughout the height of the stairwell. The locations of the measurement points can be seen in Figure 3.3-2. The events that occurred during the experiment are listed on the top of the figures with lines at the time of the event. A time history for each thermocouple at each measurement location is located in Appendix D – Detailed Graphs.

Figure 3.3-18 shows the temperatures versus time at 2.1 m (7 ft) above the floor at 5 measurement locations, the bedroom, just outside the fire apartment in the corridor, just outside Apartment 7A in the corridor, just outside the A stairwell doorway, and just inside the A stairwell on the landing. The temperature in the bedroom rose to approximately 500 ºC (932 ºF) before the bottom right window pane failed. This influx of cool air lowered the bedroom temperature to below 200 ºC (392 ºF) and slowed fire growth. It took until about 550 s until the fire in the bedroom really got developed and approached flashover. At 600 s the bedroom 2.1 m (7 ft) temperature exceeded 600 ºC (1112 ºF) and it remained above that temperature until approximately 1400 s when the fuel load in the bedroom was burning down.

The three temperature measurement locations in the corridor behaved similarly in reaction to the events with the higher temperatures at positions closer to the fire apartment. Corridor temperatures reached 400 ºC (752 ºF) before they became ventilation limited between 700s and 1100 s. Temperatures in the corridor remained very steady until a ventilation path was created. The 7$^{th}$ floor stair door was opened 0.08 m (3 in) at 1100 s which caused the corridor temperature outside the fire apartment to increase from approximately 400 ºC (752 ºF) to 550 ºC (1022 ºF). The temperatures declined again due to the lack of oxygen until the bulkhead door was opened. Once opened a wind driven condition developed increasing the corridor temperatures to above 600 ºC (1112 ºF). The temperatures decreased when the bulkhead door was closed and the PPV fan was flowing.

The temperature in the stairwell remained near ambient until the window in the bedroom failed. The stairwell temperature at 2.1 m (7 ft) above the landing increased to above 250 ºC (482 ºF) even with the door closed. The fan activation decreased this temperature back down to ambient. When the stair door was opened 0.08 m (3 in) at 1100 s the stairwell temperature increased to 300 ºC (572 ºF). After the bulkhead was opened and the wind driven conditioned developed the stair temperature exceeded 500 ºC (932 ºF). Closing the bulkhead and allowing the fan to pressurize caused the stair temperature to decrease.

Figure 3.3-19 shows the temperatures at 1.2 m (4 ft) which would be more representative to where firefighters would be operating or occupants would be evacuating. The bedroom temperature increased to 500 ºC (932 ºF) before the bedroom window partially failed, cooling the room. The temperatures cooled due to the failing windows and then the 1.2 m (4 ft) temperature began to track with the 2.1 m (7 ft) temperature after 600 s which indicated flashover conditions in the bedroom. The 1.2 m bedroom temperature remained above that temperature until approximately 1400 s when the fire in the bedroom began to decay.

Corridor temperatures reached approximately 300 ºC (572 ºF) to 600 ºC (1112 ºF) before they became ventilation limited between 700s and 1100 s. Temperatures in the corridor remained very steady until a ventilation path was created. The 7th floor stair door was opened 0.08 m (3 in) at 1100 s which caused the corridor temperature outside the fire apartment to increase from 350 ºC (662 ºF) to more than 600 ºC (1202 ºF). The temperatures decreased again with the lack of oxygen until the bulkhead door was opened. Once opened a wind driven condition developed increasing the corridor temperatures to above 800 ºC (1472 ºF). The temperatures decreased when the bulkhead door was closed and the PPV fan was flowing.

The temperature in the stairwell remained near ambient until the window in the bedroom failed. The stairwell temperature at 2.1 m (7 ft) above the landing increased to above 250 ºC (482 ºF) even with the door closed. The fan activation decreased this temperature back down to ambient. When the stair door was opened 0.08 m (3 in) at 1100 s the stairwell temperature increased to 250 ºC (482 ºF). After the bulkhead was opened and the wind driven conditioned developed the stair temperature exceeded 500 ºC (932 ºF). Closing the bulkhead and allowing the fan to pressurize caused the stair temperature to decrease.

Figure 3.3-20 shows the temperatures 1.2 m (4 ft) above the landing on floors 1, 2, 4, and at bulkhead. The thermocouple on the sixth floor failed to work. After the window failed hot gases were forced around the cracks in the stairwell door, increasing the temperature at the bulkhead door to 180 ºC (356 ºF). The fan was activated and the bulkhead was opened lowering the temperature to ambient. Prior to fan activation temperatures were increasing all the way down to the first floor. After the fan was activated the temperatures below the 4th floor never elevated above ambient.

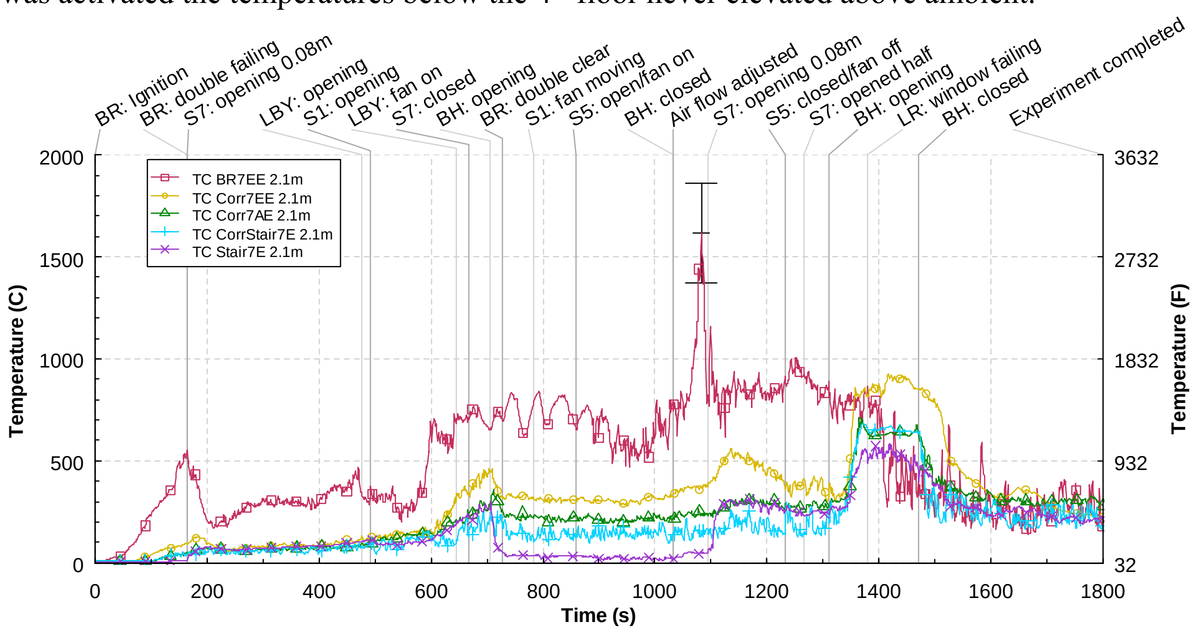



**Figure 3.3-18. 7E Temperature vs. time at 2.1 m above the floor**

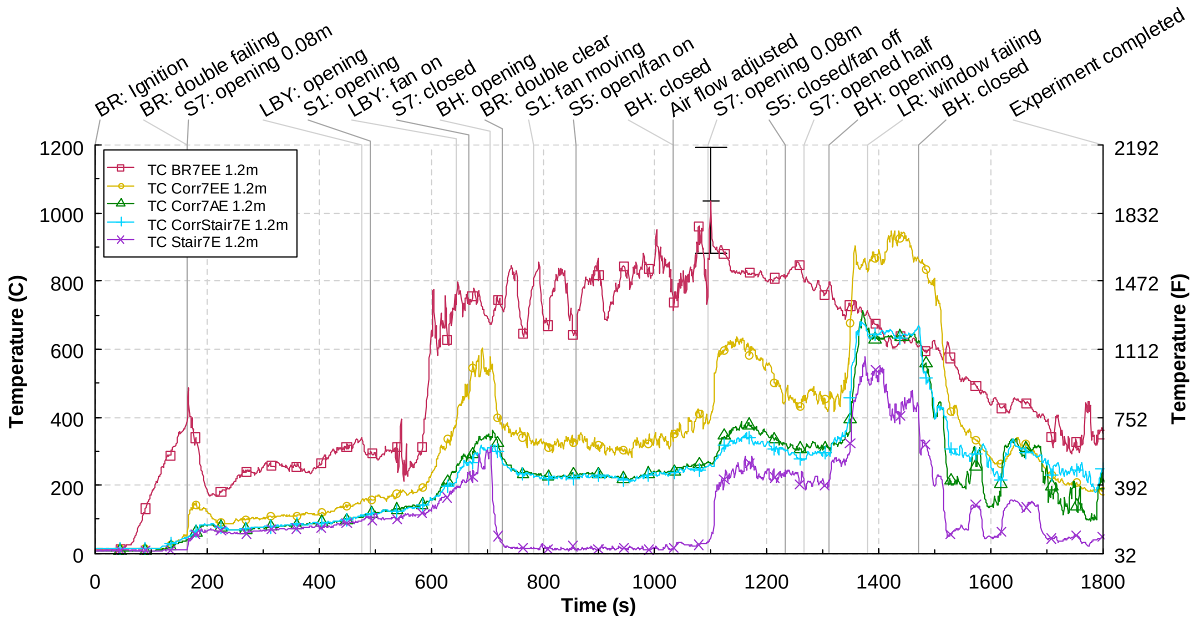



**Figure 3.3-19. 7E Temperature vs. time at 1.2 m above the floor**

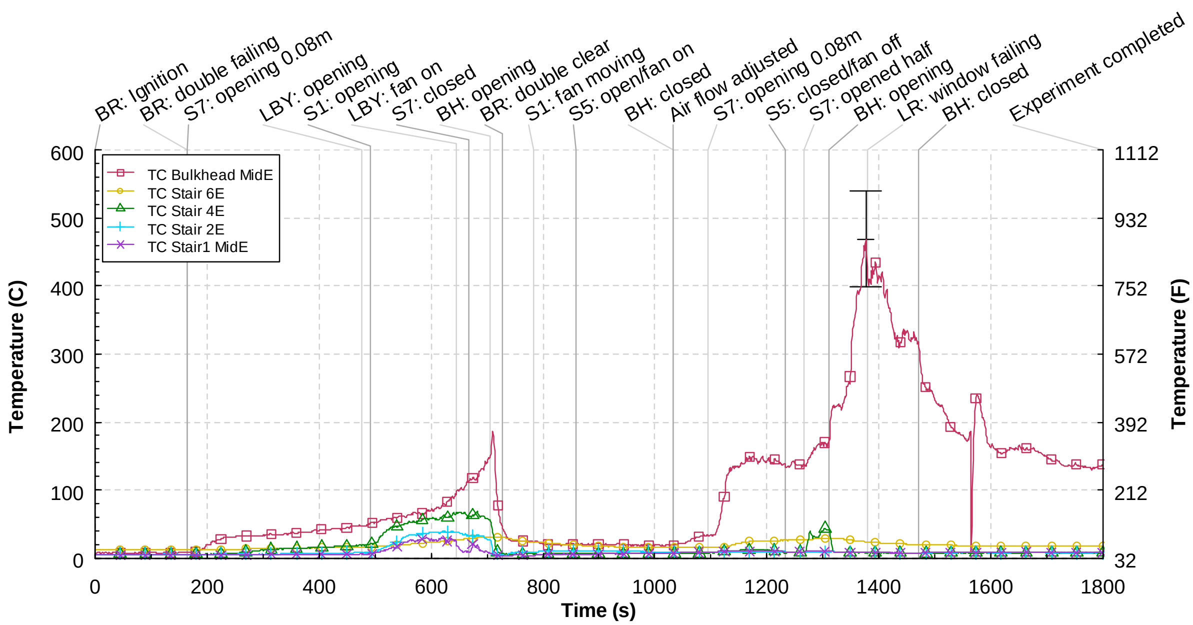



**Figure 3.3-20. 7E stairwell temperature vs. time**

## 3.3.3 Pressures

Average pressure measurements in the stairwell are shown in Figure 3.3-21. The differential pressure measurements were made at 1.2 m (4 ft) on the stairwell landing of every floor and referenced to an apartment on the same floor. With all of the doors to the stairwell closed the pressures remained below 5 Pa and only fluctuated slightly. Once the bottom right window pane failed in the bedroom the pressures in the stairwell increased to approximately 12 Pa and steadily increased to 35 Pa to 45 Pa. Next, the front lobby doors and first floor stair door were opened. This allowed the pressure to vent and created a flow out of the first floor lobby. At 600 s the pressures from top to bottom on each floor were

40 Pa, 30 Pa, 24 Pa, 16 Pa, 11 Pa, 8 Pa and 5 Pa respectively. A fan was added at the front lobby due to the smoke coming out of the front doors, which increased the pressure in the stair further. The bulkhead door was opened and the pressure in the entire stair dropped below 10 Pa as the gases moved to the vent.

After the smoke moved up the stairwell, the fan was moved from the lobby to the base of the stairwell. This increased the stairwell pressures to a range of 5 Pa to 18 Pa. Adding a second PPV fan at floor 5 increased the stairwell pressure range to 5 Pa to 22 Pa. The bulkhead door was closed and the stairwell pressure range increased to from 5 Pa to 30 Pa. Opening the fire floor door 0.08m (3 in) and allowing more wind driven flow into the stair increased the pressure range further to 20 Pa to 44 Pa. With the fire floor door completely opened the pressure range was 20 Pa to 58 Pa. After the living room window failed and the flow was split the pressures became steadier at 16 Pa to 24 Pa.

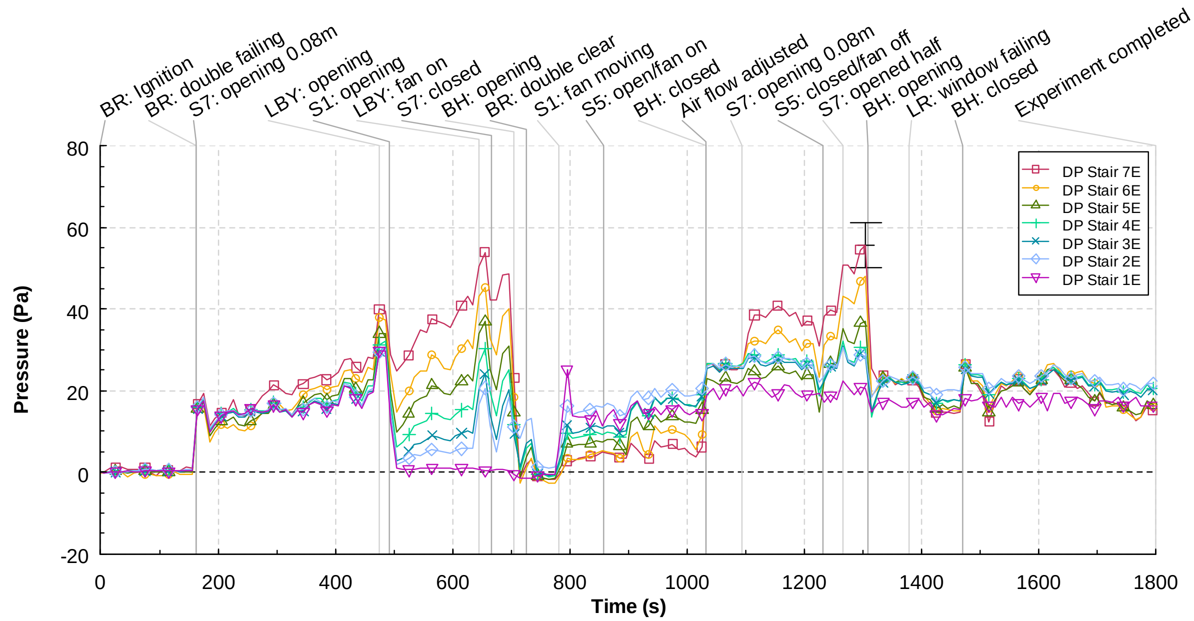



**Figure 3.3-21. 7E stairwell pressures vs. time**

### 3.3.4 Velocities

Average doorway velocities from 4 doors; the fire apartment door, the door from the fire floor to the stairwell, the door at the base of the stair and the door at the bulkhead, were recorded versus time and shown in Figure 3.3-22. The three bi-direction probes in each door were averaged to provide the bulk flow through the doors. A time history for each probe at each measurement location is located in Appendix D – Detailed Graphs.

The flows out of the fire apartment were as high as 5 m/s with the stairwell door closed. When the bulkhead door was opened with the fan flow the bulk flow velocity out of the top of the stairwell peaked at 4 m/s. The flow out of the fire apartment with the stairwell opened was approximately 5 m/s and increased to 20 m/s with the bulkhead door opened. The flow into the stairwell was approximately 9 m/s and the flow out of the bulkhead door was 13 m/s with the wind driven flow combined with the PPV fan flow.

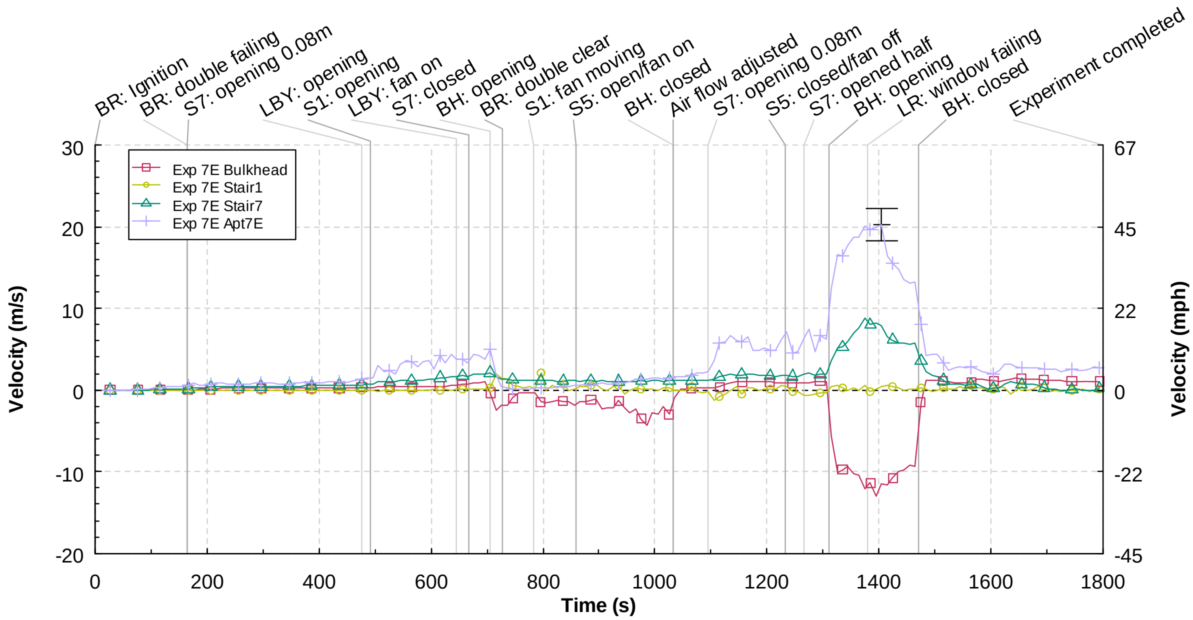



**Figure 3.3-22. 7E Velocities vs. time**

### 3.3.5 Discussion

Experiment 7E was the first experiment to introduce a simulated wind. A wind driven fire was created but it took some coordinated opening of doors to get the conditions right, but when the wind driven condition was created it forced flames all the way from the ignition bedroom to the stairwell door in the corridor. These conditions would not be conducive to an interior direct frontal fire fighter attack. The missing inner pane of the bedroom window caused much earlier failure as compared to experiment 7G. One of the bedroom windows failed at 165 s causing cooling which delayed the wind driven condition and other window failure, but when the conditions developed the area in the vent path became untenable very quickly. The entire bedroom double window was failed at 729 s.

At approximately 700 s, the bedroom is fully involved in fire (post-flashover). Even though temperatures in the bedroom were in excess of 600 ºC (1112 ºF), the temperatures in the public hall and the stair were well below that but increasing. This was mainly due to the fact that there was no flow path for the fire gases to follow because the door to the stair was closed. Even with the door closed, there was enough leakage to increase the temperatures significantly in the stairwell and at the top of the stairs. Opening the bulkhead door, with the fire floor closed improved conditions in the stairwell. Opening the bulkhead door, with the fire floor door open deteriorated conditions in the entire flow path from the bedroom to the top of the stairs. When the first floor was open and the fire floor door and bulkhead door were closed the gases forced around the fire floor door traveled down the stairs and exited the front of the building 7 floors below. This flow path greatly decreases safety of occupants evacuating and requires fire fighters to utilize their SCBA (self contained breathing apparatus) upon entering the structure. In addition, visibility was limited on all 7 floors of the stairwell which would slow fire department operations.

The use of the PPV fans greatly improved conditions in the stairwell. They were not able to keep them completely free of smoke under wind driven conditions but they were very effective and moving the flow up the stairwell and holding the smoke and hot gases when the fire floor door was closed. With the door open the flow was slowed but not stopped. After the bulkhead door was opened the temperatures in the public hall and the stair continued to increase until the fan was moved into place at the base of the stair on the first floor. Then the 5th floor door was opened and another fan was added at that location. It is important to note the temperatures in the stair were reduced and kept at ambient conditions with two fans. A small increase in temperature occurred when the stair door on the 7th floor was opened 3 inches. Turning off the fan on 5 and opening the stair door on the 7th floor results in a significant temperature increase in the stair. Opening the bulkhead door at approximately 1370 s, was followed by ignition of the sofa in the living room. This increased the temperature in the public hallway until the living room window self vents and the bulkhead was closed. At this point the single 27 inch fan on the first floor was working to cool the stair and the public hall by pushing air back to Apartment 7E.

## 3.4 Experiment 7A

The fourth experiment in the structure was located on the 7th floor in apartment 7A. Experiment 7A was ignited in the bedroom furthest from the open apartment door (Figure 3.4-1). This experiment also utilized a simulated wind provided by the MVU. The simulated wind was subjected to the bedroom double window at a magnitude of approximately 9 m/s to 11 m/s (20 mph to 25 mph). The middle bedroom was also furnished and its door remained open during the experiment. The events that took place during the experiment to accomplish the experimental objectives below are shown in Table 3.4-1.

Experimental Objectives

- Create wind driven fire conditions from a bedroom fire
- Examine window failure times and conditions
- Examine building flows with different door opening configurations
- Examine impact of the deployment of a WCD on fire room window
- Utilize portable PPV fans to control smoke movement

The results for the experiment are presented in the following sections: observations, temperature, pressure, velocity, and discussion. Figure 3.4-2 shows the camera names and locations used in the observation section and the instrumentation names and locations used in the temperature, pressure and velocity sections.

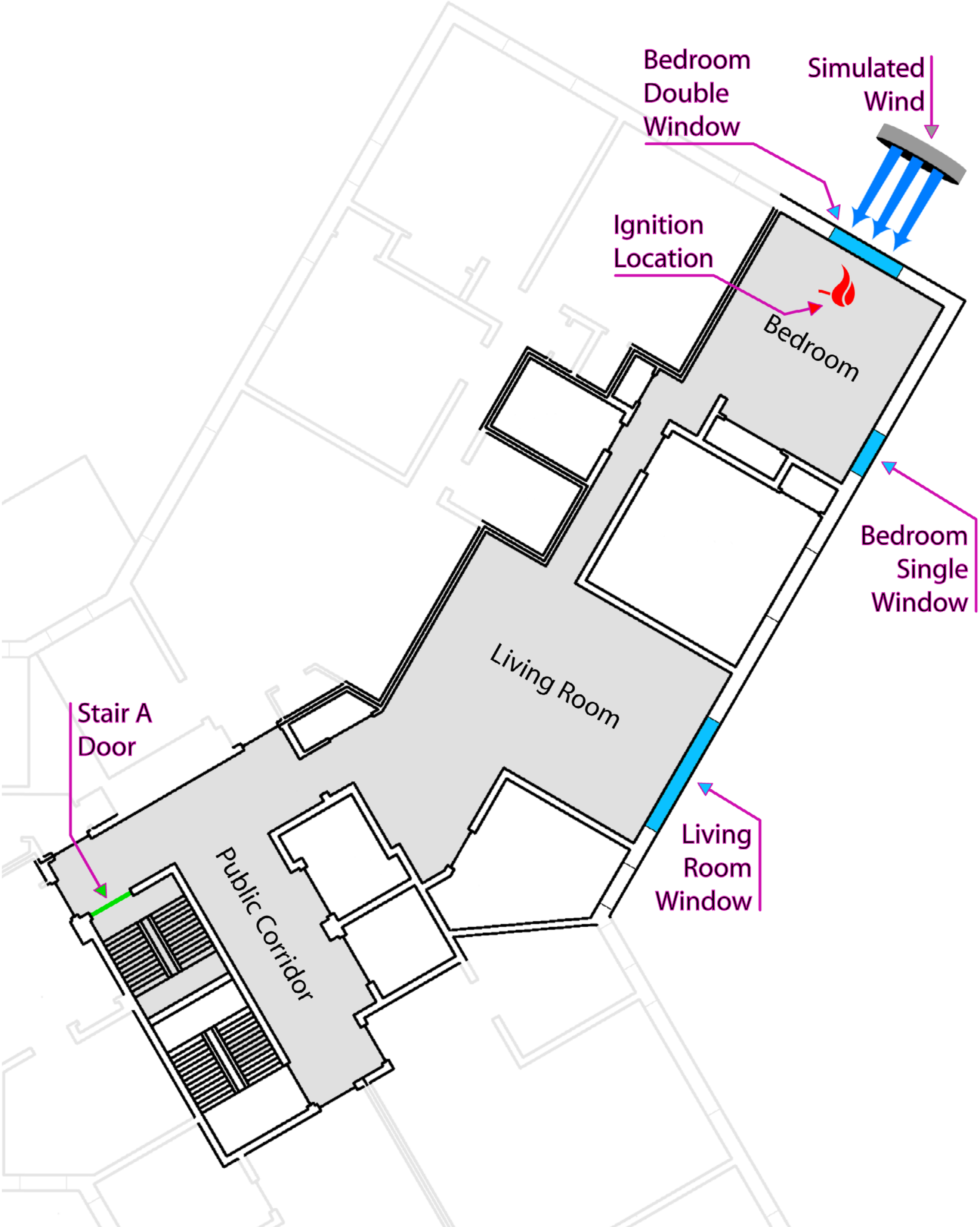



**Figure 3.4-1. 7th floor apartment A floor plan with locations pertinent to Experiment 7A**

**Table 3.4-1: Experiment 7A Timeline**

| Start (s) | End (s) | Event Location | Event Description |
|---|---|---|---|
| 0 | 0 | Bedroom | Ignition |
| 282 | 286 | 7th floor stair A | Door opened and closed |
| 316 | 316 | Bedroom double | Bottom right pane failed |
| 432 | 433 | Bedroom double | Top right pane failed |
| 453 | 454 | Bedroom double | Bottom left pane failed |
| 587 | 596 | Front lobby | Doors opened |
| 608 | 609 | Bedroom double | Top left pane failed |
| 615 | 620 | 1st floor stair A | Door opened |
| 684 | 686 | Bulkhead door | Opened |
| 746 | 749 | 7th floor stair A | Door opened (1/2) |
| 813 | 825 | 7th floor stair A | Door closed |
| 840 | 848 | Bedroom double | WCD partially deployed |
| 896 | 904 | Bedroom double | WCD fully deployed |
| 984 | 986 | 7th floor stair A | Door opened 0.08 m (3 in) |
| 1056 | 1060 | 7th floor stair A | Door opened |
| 1089 | 1091 | 7th floor stair A | Door closed |
| 1128 | 1135 | 1st floor stair A | 27 inch fan activated |
| 1168 | 1170 | Bulkhead door | Closed |
| 1194 | 1199 | 7th floor stair A | Door opened |
| 1311 | 1314 | Living room window | Pane failed |
| 1324 | 1325 | Living room window | Pane failed |
| 1327 | 1328 | Living room window | Pane failed |
| 1344 | 1344 | Living room window | Pane failed |
| 1356 | 1356 | Living room window | Pane failed |
| 1647 | 1647 | Bedroom double | FBN 2 started flowing (Fog) |
| 1772 | 1793 | Bedroom double | WCD removed |
| 1932 | 1932 | Bedroom double | FBN 2 stopped |
| 2011 | 2016 | 1st floor stair A | 27 inch fan deactivated |
| 2092 | 2096 | 1st floor stair A | 27 inch fan activated |
| 2534 | 2534 | Experiment completed | |

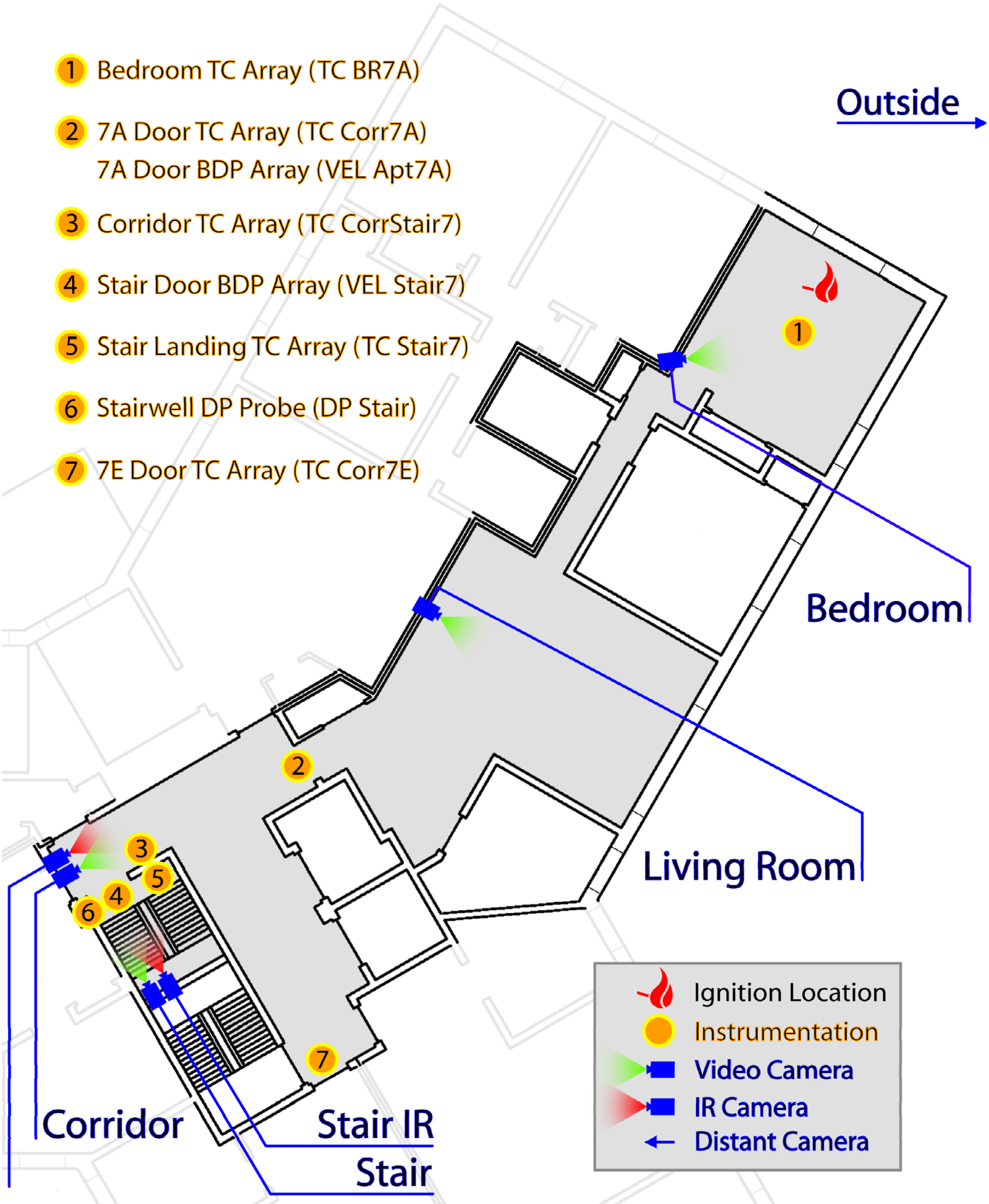



Figure 3.4-2. Instrumentation and camera locations with labels.

### 3.4.1 Observations

The observations are presented as a series of images captured from eight camera locations, six were video cameras and two were thermal imaging cameras. The camera positions inside the building are shown in Figure 3.4-2.

Figure 3.4-3 through Figure 3.4-21 present sets of eight images one from each camera position, at a given time, from the time of ignition to 40 min (2400 s) after ignition. Images were captured every 4 min and at times when events had taken place that demonstrate the experimental objectives. Each image view is labeled. The first view (BEDROOM) at the top left of each figure shows the bedroom of apartment 7A, the bedroom furthest from the apartment entrance with a view of the single window straight across, double window to the right and ignition trashcan at the foot of the bed. The top right view (LIVINGRM) was of the living room looking across to the windows. The corridor and corridor thermal imaging views (CORRIDOR and CORR IR) show the corridor leading up to the open apartment doorway; the corridor IR had been damaged in the previous experiment and was not functioning properly, however it does provide some information. The next two views (STAIR and STAIR IR) show the stairwell with a visual and a thermal imaging camera from the floor below the fire looking up to the fire floor. The bottom left view (ROOF) shows the bulkhead door at the top of the stairwell and the bottom right view (OUTSIDE) shows an external view of the fire apartment.

Figure 3.4-3 shows the images at the time of ignition. At this point, the six video views were clear and unobstructed. The corridor thermal imaging camera was also damaged from the previous experiment but still had a view so it was included in the recording. This experiment shares the corridor from Experiment 7E so the corridor is thermally damaged and there is a bit of a lingering haze of smoke in the living room.

Figure 3.4-4 shows the images at 240 s (4 min) after ignition. The smoke layer descended to the floor throughout the 7A apartment and the public corridor. The stairwell, which was closed at the $7^{th}$ floor, remained clear of smoke. The outside view shows all of the windows intact and the fire fighting crew in place to deploy a WCD.

Figure 3.4-5 shows the images at 480 s (8 min) after ignition. The $7^{th}$ floor stair A door had been opened and closed 194 s prior, this had allowed a significant volume of smoke into the stairwell; visibility in the stairwell view had reduced to zero. The right side of the bedroom double window had failed in three sections 164 s, 47 s, and 26 s prior and the fire had progressed significantly in the bedroom. The increasing temperature of the $7^{th}$ floor stair A door was visible in the stair IR view.

Figure 3.4-6 shows the images at 630 s (10 min and 30 s) after ignition. The bedroom had become fully involved in flame and the view in the living room was obscured by soot. Flames were visible leaving the fire apartment and entering the corridor. Visibility was lost in the stairwell and heat was being forced around the gaps in the doorway. Flames are visible at the bedroom window but all smoke and flames are being forced into the window by the simulated wind.

Figure 3.4-7 shows the images at 720 s (12 min) after ignition. The bulkhead door had been opened 35 s prior. Flames were pushing into the public corridor through the apartment entrance. The stairwell, which was closed at the 7$^{th}$ floor, was clearing of smoke below the fire floor as the smoke moved up through the open bulkhead doorway. More flames are visible at the bedroom window but all smoke and flames are being forced into the window by the simulated wind.

Figure 3.4-8 shows the images at 780 s (13 min) after ignition. Flames now involved the entire apartment from the bedroom, through the living room and extended into the corridor. Hot gases were flowing into the stairwell as shown in the stairwell thermal imaging camera. The corridor thermal imaging camera shows high heat levels but there is no usable image.

Figure 3.4-9 shows the images at 910 s (15 min and 10 s) after ignition. The WCD was deployed and positioned over the bedroom double window blocking the wind exposure. The bedroom was fully involved in flames and the living room view was still obscured by smoke. The corridor and corridor IR camera failed due to thermal exposure from the wind driven fire. The conditions in the stairwell improved substantially with visibility returning and all of the combustion products venting vertically through the open bulkhead doorway. The stairwell door had been closed slowing the flow into the stairwell.

Figure 3.4-10 shows the images at 960 s (16 min) after ignition. None of the fire floor was visible from the video views. The closed stairwell remained clear below the fire floor but smoke was leaking around the stair door and flowing through the open bulkhead doorway.

Figure 3.4-11 shows the images at 1080 s (18 min) after ignition. The 7$^{th}$ floor stair A door had been fully opened 20 s prior and the smoke is flowing into the stairwell similar to Experiment 7G, when there was no wind effects. The fire in the bedroom was visible again and it was burning toward the window where some air was leaking in through the bottom of the blanket where it was not completely sealed over the window.

Figure 3.4-12 shows the images at 1200 s (20 min) after ignition. The bulkhead door had been closed 30 s prior and stairwell A was being pressurized by a 27 inch fan placed at the 1$^{st}$ floor entrance to that stairwell. No smoke was visible in the stair view and no smoke was leaking from the bulkhead door.

Figure 3.4-13 shows the images at 1440 s (24 min) after ignition. The living room window had begun to fail 129 s prior. There was still no smoke or heat flow in the stairwell. The WCD was continuing to hold up to the extreme temperatures it was being subjected to. The silver coating on the WCD was missing in spots but the WCD itself was still completely intact to stop the wind.

Figure 3.4-14 shows the images at 1680 s (28 min) after ignition. FBN 2 was inserted into the bottom of the window and started flowing water 32 s prior, but no visible change is apparent in the bedroom or living room views because they are obscured by soot deposition.

Figure 3.4-15 shows the images at 1830 s (30 min and 30 s) after ignition. The WCD had been removed 40 s prior and the FBN was continuing to flow. The bulk of the fire was extinguished in the bedroom but flames are still visible in the living room. Conditions remained the same in the stairwell with the portable PPV fan continuing to keep it free of smoke and heat.

Figure 3.4-16 shows the images at 1920 s (32 min) after ignition. The FBN 2 was continuing to flow into the ignition bedroom, and without the WCD, visibility was improved in that view. Flames only continued to burn on a shielded item in the corner of the bedroom. A red glow was still visible in the living room view but no heat was being forced into the stairwell.

Figure 3.4-17 shows the images at 2010 s (33 min and 30 s) after ignition. Suppression had stopped. The portable fan was still operating at the base of the stairwell. Figure 3.4-18 shows the images at 2090 s (34 min and 50 s) after ignition. This was approximately 75 s after the fan was turned off and the smoke was being forced into the stairwell, reducing visibility. Figure 3.4-19 shows the images at 2120 s (35 min and 20 s), 25 s after the fan was turned back on clearing the stair of smoke.

Figure 3.4-20 shows the images at 2160 s (36 min) after ignition and Figure 3.4-21 shows the images at 2400 s (40 min) after ignition. No significant change in conditions was visible; the fan continued to keep the stairwell free of smoke while the fire was allowed to burn down.


**Figure 3.4-3. Experiment 7A, ignition.**


**Figure 3.4-4. Experiment 7A, 240s after ignition.**

Figure 3.4-5.  Experiment 7A, 480s after ignition.

Figure 3.4-6. Experiment 7A, 630s after ignition.

Figure 3.4-7. Experiment 7A, 720s after ignition.

Figure 3.4-8.  Experiment 7A, 780s after ignition.

Figure 3.4-9. Experiment 7A, 910s after ignition.

Figure 3.4-10. Experiment 7A, 960s after ignition.


**Figure 3.4-11. Experiment 7A, 1080s after ignition.**

Figure 3.4-12. Experiment 7A, 1200s after ignition.

Figure 3.4-13. Experiment 7A, 1440s after ignition.

Figure 3.4-14. Experiment 7A, 1680s after ignition.

Figure 3.4-15. Experiment 7A, 1830s after ignition.

Figure 3.4-16. Experiment 7A, 1920s after ignition.

Figure 3.4-17. Experiment 7A, 2010s after ignition.


**Figure 3.4-18. Experiment 7A, 2090s after ignition.**

Figure 3.4-19. Experiment 7A, 2120s after ignition.

**Figure 3.4-20. Experiment 7A, 2160s after ignition.**

**Figure 3.4-21. Experiment 7A, 2400s after ignition.**

### 3.4.2 Temperatures

Figure 3.4-22 through Figure 3.4-24 provide temperature data for five measurement locations on the fire floor at two elevations and throughout the height of the stairwell. The locations of the measurement points can be seen in Figure 3.4-2. The events that occurred during the experiment are listed on the top of the figures with lines at the time of the event. A time history for each thermocouple at each measurement location is located in Appendix D – Detailed Graphs.

Figure 3.4-22 shows the temperatures versus time at 2.1 m (7 ft) above the floor at 5 measurement locations, the bedroom, just outside the fire apartment in the corridor, just outside Apartment 7E in the corridor, just outside the A stairwell doorway, and just inside the A stairwell on the landing. The temperature in the bedroom increased to more than 450 ºC (842 ºF) until a window pane failed lowering the temperature. The temperature recovered and then two more panes failed decreasing the bedroom temperature again. At approximately 540 s the bedroom transitioned to flashover, quickly driving the bedroom temperature to above 800 ºC (1472 ºF). The WCD was deployed and the bedroom temperature increased briefly until it was completely in place, blocking the entire window, and then decreased from 1000 ºC (1832 ºF) to below 500 ºC (932 ºF) in 180 s.

The 2.1 m (7 ft) temperatures in the corridor measurement locations slowly increased as the fire in the bedroom grew. As the bedroom flashed over and a wind driven condition was developed the corridor temperatures increased to above 600 ºC (1112 ºF). After the WCD was in place the corridor temperatures decreased from over 600 ºC (1112 ºF) to below 300 ºC (572 ºF) in 100 s. These temperatures recovered up to almost 400 ºC (932 ºF) before the FBN was activated and the WCD was removed lowering the temperatures.

The 2.1 m (7 ft) temperature in the stairwell increased as hot gases were forced into the stairwell from gaps around the door. The 7$^{th}$ floor door was opened at 750 s which caused the stairwell temperature to increase from 150 ºC (302 ºF) to 700 ºC (1292 ºF) in seconds. Closing the door and the deployment of the WCD drove the temperature back down to below 200 ºC (392 ºF). A portable PPV fan was activated and that kept the stairwell below 150 ºC (302 ºF) for the remainder of the experiment.

Figure 3.4-23 shows the temperatures at 1.2 m (4 ft) which would be more representative to where firefighters would be operating or occupants would be evacuating. These temperatures behaved very similarly to the temperatures at 2.1 m (7 ft) after the wind driven condition was developed. This indicates that after that time there was a uniform well mixed environment. After deployment of the WCD the 1.2 m (4 ft) temperatures in the corridor dropped to 100 ºC (212 ºF) to 200 ºC (392 ºF) below the 2.1 m (7 ft) temperatures re-establishing a two layer environment by removing the impact of the wind.

Figure 3.4-24 shows the temperatures 1.2 m (4 ft) above the landing on floors 1, 2, 4, 6 and at the bulkhead. The temperatures below the fire floor remained at ambient during the entire experiment. While the wind driven condition was flowing into the stairwell the bulkhead door was opened allowing the hot gases to flow up the stairwell. The temperature at the bulkhead door increased to 100 ºC (212 ºF) until the bulkhead door was opened. The temperature dropped briefly and then increased to above 600 ºC (1112 ºF) quickly as the flow path was established through the open 7$^{th}$ floor door. As he fire floor door was closed the temperature at the top of the stair decreased to below 100 ºC (212 ºF).

After the PPV fan was activated the temperature remained below 100 ºC (212 ºF) for the remainder of the experiment.

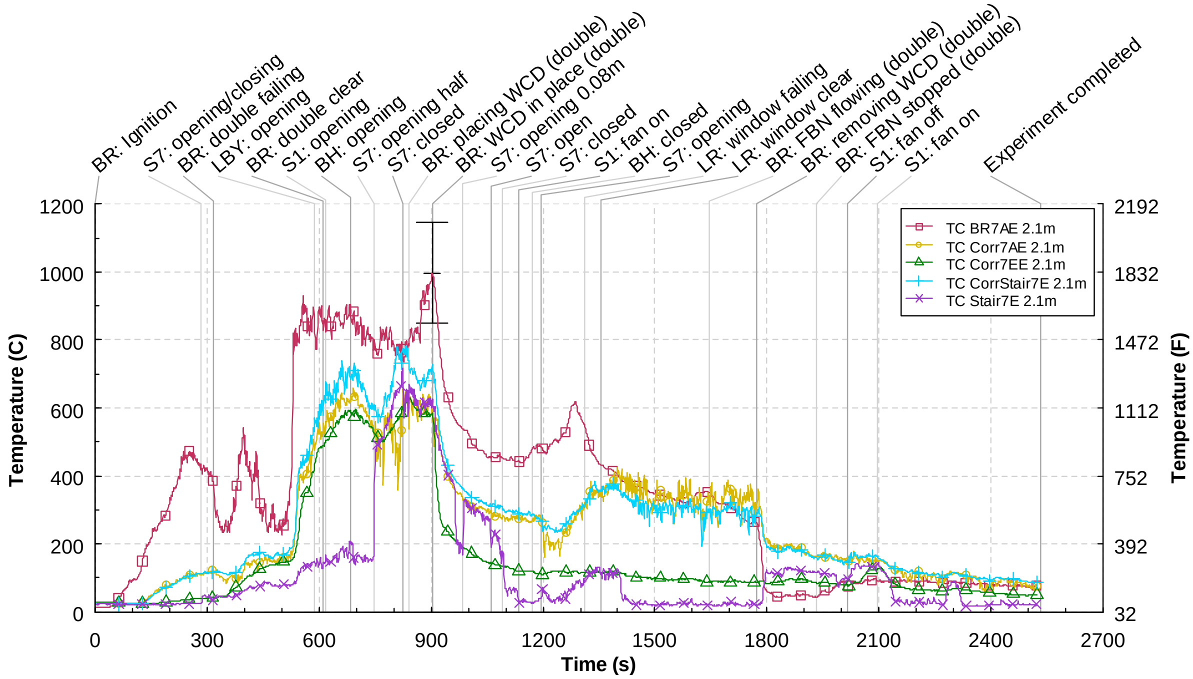



**Figure 3.4-22. 7A Temperature vs. time at 2.1 m above the floor**

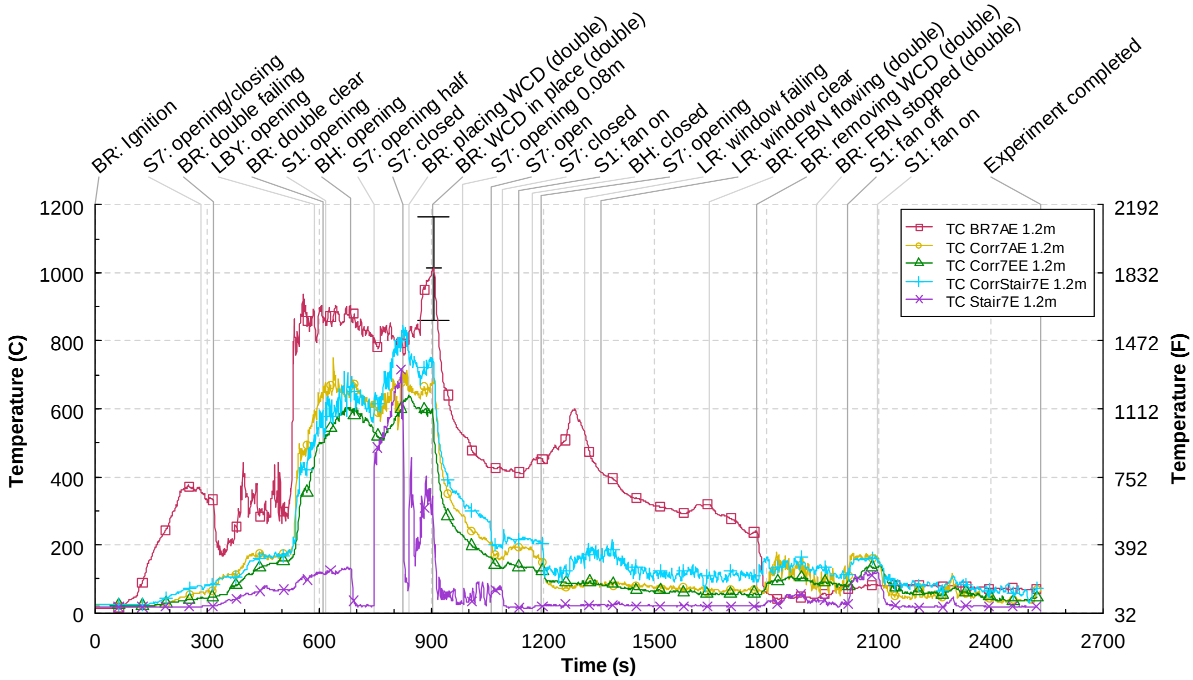



**Figure 3.4-23. 7A Temperature vs. time at 1.2 m above the floor**

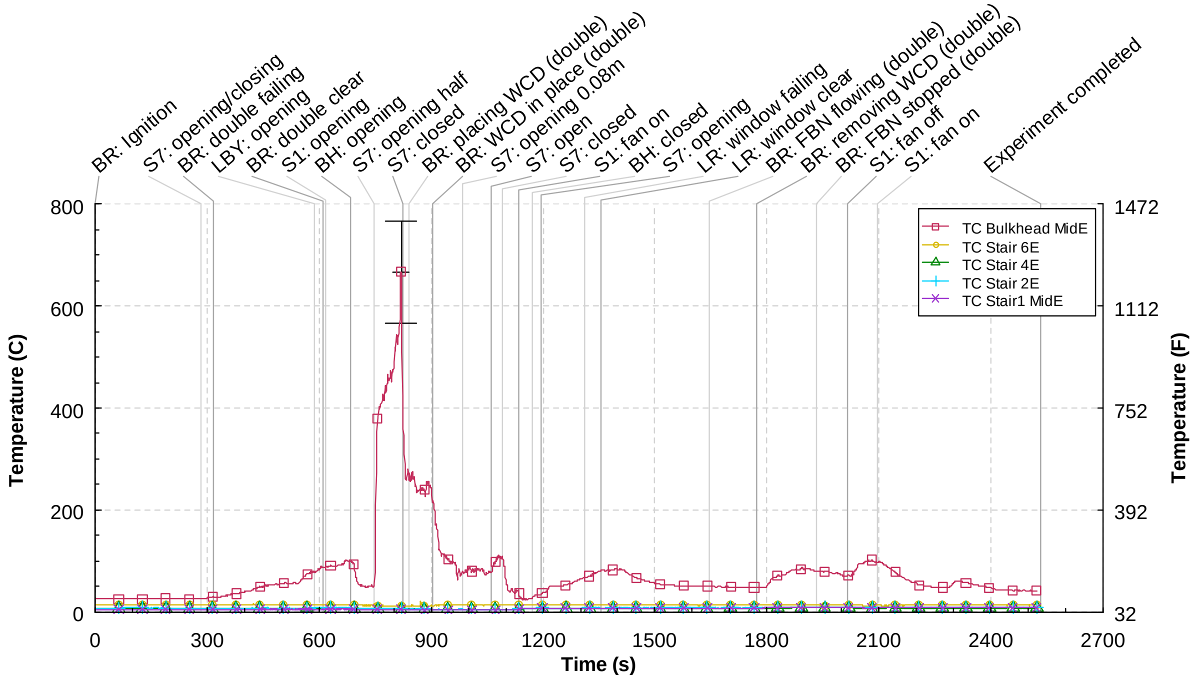



**Figure 3.4-24. 7A stairwell temperature vs. time**

### 3.4.3 Pressures

Average pressure measurements in the stairwell are shown in Figure 3.4-25. The differential pressure measurements were made at 1.2 m (4 ft) on the stairwell landing of every floor and referenced to an apartment on the same floor. With all of the doors to the stairwell closed the pressures remained below 2 Pa and only fluctuated slightly. After the bedroom window began to fail the wind that leaked around the gaps in the stairwell door increased the pressure in the closed stairwell to closer to 5 Pa. The base of the stair was opened which dropped the pressure and the bulkhead was opened which dropped the pressures to close to zero. There was a spike to 12 Pa in the 7$^{th}$ floor stairwell pressure when the door was opened at 750 s. The stairwell was opened again after the WCD was deployed and there was no significant increase in stairwell pressure. At 1135 s a portable PPV fan was activated increasing the stairwell pressures from 5 Pa to 25 Pa depending on the distance from the fan. These pressures were with the 7$^{th}$ floor door to the stair open. At 1790 s the WCD was removed increasing the pressures in the stair to 15 Pa to 22 Pa. There was no pressure increase at floors 1 and 2. Turning the fan off decreased the pressures to below 8 Pa throughout the stairwell and turning it back on returned the pressures back to previous levels.

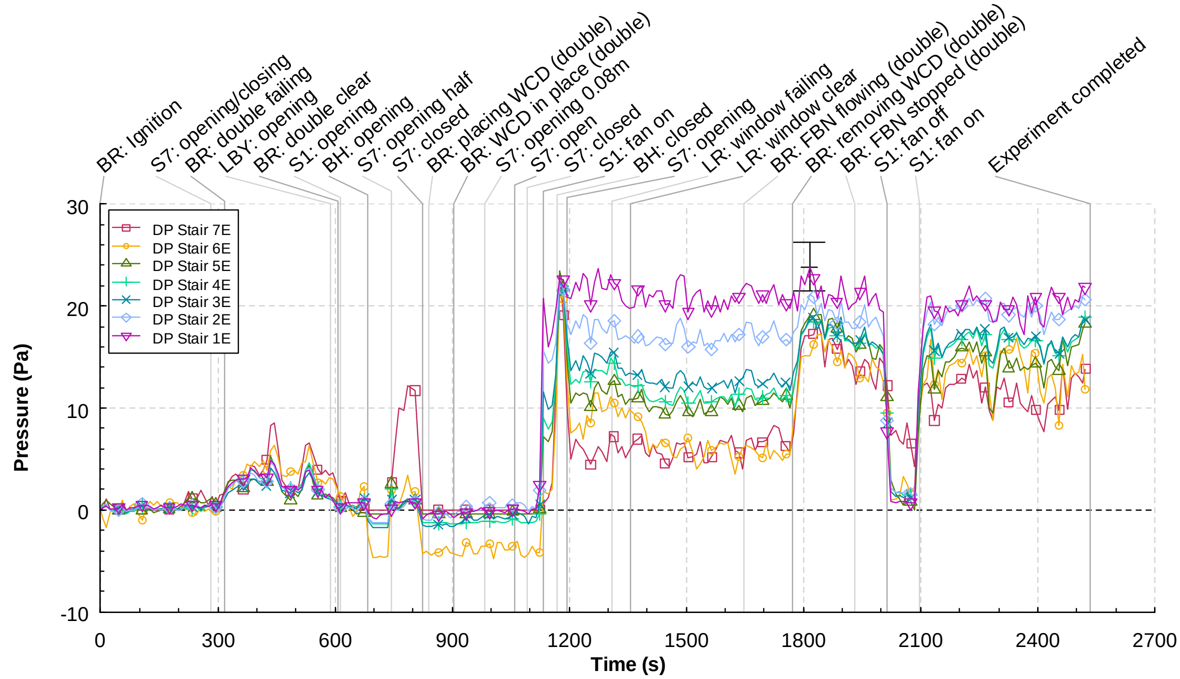



**Figure 3.4-25. 7A stairwell pressures vs. time**

### 3.4.4 Velocities

Average doorway velocities from 4 doors; the fire apartment door, the door from the fire floor to the stairwell, the door at the base of the stair and the door at the bulkhead, were recorded versus time and shown in Figure 3.4-26. The three bi-direction probes in each door were averaged to provide the bulk flow through the doors. A time history for each probe at each measurement location is located in Appendix D – Detailed Graphs. The velocity out of the open apartment door steadily increased as the fire grew. Opening the 7$^{th}$ floor stair door initiated the wind driven condition which had a peak velocity of 21 m/s (45 mph). The velocity into the stairwell and out of the top of the stairwell peaked at approximately 12 m/s (27 mph). After the WCD was deployed the velocities decreased even with the stairwell doors open which would be expected. With the use of the fan, the velocities were less than 2 m/s (4 mph) toward the fire apartment.

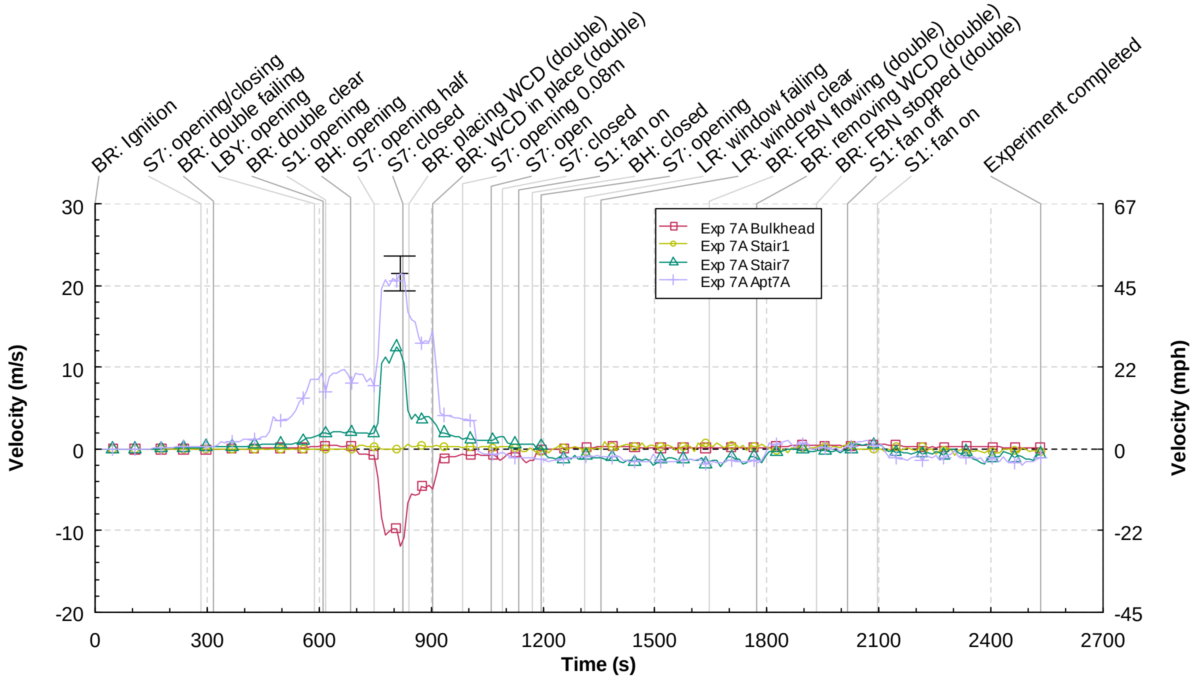



**Figure 3.4-26. 7A Velocities vs. time**

### 3.4.5 Discussion

Experiment 7A utilized a simulated wind created by the MVU. A wind driven fire was created from the fire ignited in the bedroom. Flames were forced out of the apartment and into the corridor with the stair door closed and conditions worsened further when the stairwell door was opened allowing the hot gases to flow throughout the stairwell. These conditions would not be conducive to an interior direct frontal fire fighter attack. Stairwell temperatures were in excess of 600ºC (1112 ºF) with the door open.

The first pane of the bedroom window failed at 316 s and the window completely failed at 609 s. The temperature in the center of the bedroom at 1.2 m (4 ft) at the time of window failure was approximately 350 ºC (662 ºF). The temperature in the center of the room at the time of complete window failure was in excess of 800 ºC (1472 ºF). This demonstrated that when a portion of the window failed the wind being introduced through the opening can cool and slow the failure of the rest of this type of window.

This experiment highlighted the importance of door control. A wind driven condition was created on the fire floor and then the stairwell door was opened. With the bulkhead door also open the flow path between the fire floor and the top of the stairwell increased from less than 50 ºC (122 ºF) to over 400 ºC (752 ºF) in less than 15 s. The stairwell temperature peaked at 700 ºC (1292 ºF) in 35 s at which time the fire floor stairwell door was closed. Closing the door lowered temperatures to less than 200 ºC (392 ºF) quickly.

There was a small delay in getting the WCD in place, but once it was fully deployed over the window the impact was beneficial to conditions throughout the structure. Fire apartment and corridor temperatures reduced by more than half in less than 30 s. More importantly the stairwell temperatures at the fire floor were reduced to ambient from 400 ºC (752 ºF) and the stairwell temperatures above the fire floor were reduced from 250 ºC (482 ºF) to less than 100 ºC (212 ºF). Without the WCD, even with the door to the fire floor shut the stairwell at the fire floor and above became untenable for occupants as well as fire fighters as hot gases continued to be forced around the gaps around the fire floor door. These temperatures would have forced the fire fighters to stay below the fire floor with no ability to advance up the stairwell until the WCD was deployed.

The impact of the WCD was observed and then a portable PPV fan was used to control smoke and heat movement. The fan was activated at the base of the stair and the stairwell temperatures never increased above 100 ºC (212 ºF) although the corridor temperature right inside the stairwell door was in excess of 300 ºC (572 ºF). Even with the living room well involved in fire the stairwell remained free of smoke and heat with the fire floor stairwell door open. When it was briefly turned off for 78 s during the end of the experiment, the smoke moved into and down the stairwell reducing visibility. Within 30 s of restarting the fan, the stairwell was free of smoke.

## 3.5 Experiment 7K

The fifth experiment in the structure was located on the 7th floor in apartment 7K. Experiment 7K was also ignited in the bedroom furthest from the open apartment door (Figure 3.5-1). This experiment also utilized a simulated wind provided by the MVU. The simulated wind was subjected to the bedroom double window at a magnitude of approximately 9 m/s to 11 m/s (20 mph to 25 mph). The events that took place during the experiment to accomplish the experimental objectives below are shown in Table 3.5-1.

Experimental Objectives

- Create wind driven fire conditions from a bedroom fire
- Examine window failure times and conditions
- Examine building flows with different door opening configurations
- Examine impact of the deployment of a WCD on fire room window
- Utilize portable PPV fans to control smoke movement
- Control wind driven conditions with FBN

The results for the experiment are presented in the following sections: observations, temperature, pressure, velocity, and discussion. Figure 3.5-2 shows the camera names and locations used in the observation section and the instrumentation names and locations used in the temperature, pressure and velocity sections.

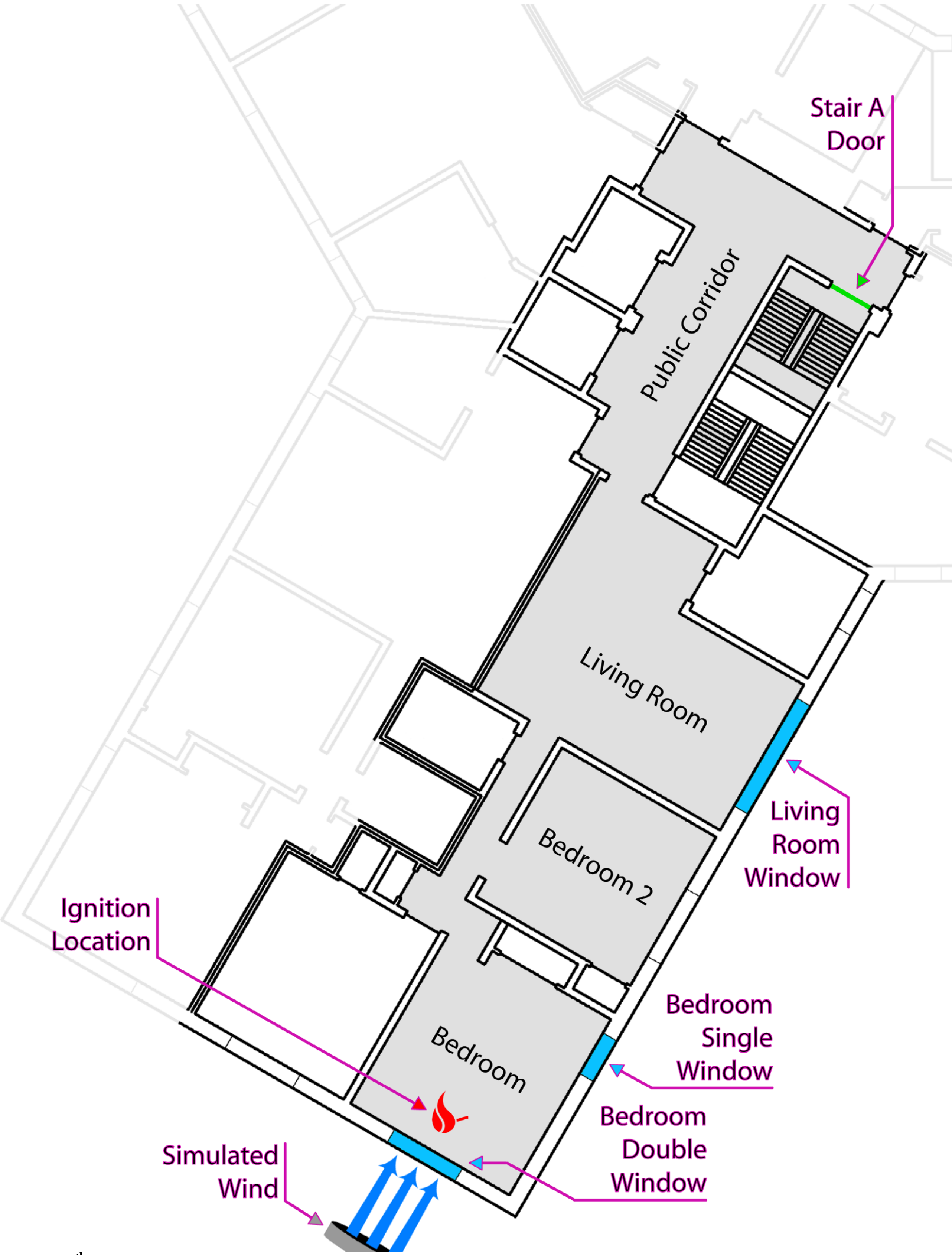



**Figure 3.5-1. 7th floor apartment K floor plan with locations pertinent to Experiment 7K**

**Table 3.5-1: Experiment 7K Timeline**

| Start (s) | End (s) | Event Location | Event Description |
|---|---|---|---|
| 0 | 0 | Bedroom | Ignition |
| 164 | 167 | 7th floor stair A | Door closed |
| 240 | 241 | Bedroom double | Bottom left pane failed |
| 240 | 241 | 7th floor stair A | Door opened 0.08 m (3 in) |
| 248 | 249 | Bedroom double | Bottom right pane failed |
| 251 | 252 | 7th floor stair A | Door closed |
| 263 | 263 | Bedroom double | Top left pane failed |
| 286 | 287 | Bedroom double | Top right pane failed |
| 327 | | Bulkhead door | Opened |
| 326 | 332 | 7th floor stair A | Door opened |
| 361 | 363 | Bulkhead door | Closed |
| 368 | 385 | Front lobby | Doors opened |
| 391 | 395 | 7th floor stair A | Door closed |
| 406 | 410 | 1st floor stair A | Door opened |
| 461 | 467 | Bulkhead door | Opened |
| 486 | 491 | 7th floor stair A | Door opened |
| 547 | 552 | 7th floor stair A | Door closed |
| 554 | 577 | Living room window | Failure, starting along top |
| 587 | 588 | Bedroom double | WCD deployed |
| 641 | 642 | 7th floor stair A | Door opened 0.08 m (3 in) |
| 669 | 672 | 7th floor stair A | Door opened |
| 733 | 738 | 7th floor stair A | Door closed |
| 766 | 777 | 1st floor stair A | 27 inch fan activated |
| 849 | 851 | Bulkhead door | Closed |
| 879 | 881 | 7th floor stair A | Door opened |
| 1505 | 1512 | Bedroom double | WCD removed |
| 1589 | 1589 | Living room window | FBN 2 started flowing (Fog) |
| 1665 | 1665 | Living room window | FBN 2 stopped |
| 1683 | | Bedroom double | Air flow removed |
| 1745 | 1745 | Experiment completed | |

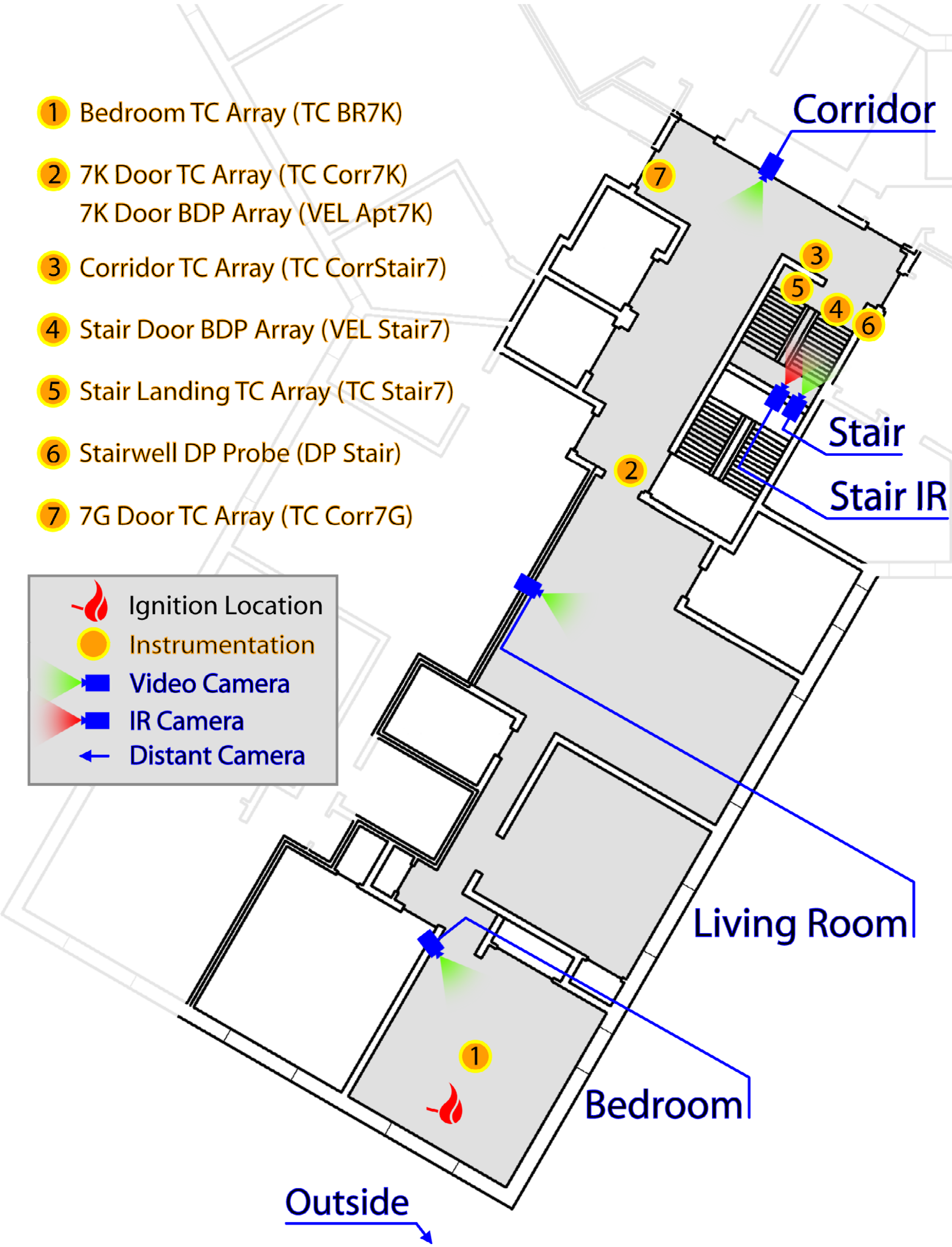



**Figure 3.5-2. Instrumentation and camera locations with labels.**

### 3.5.1 Observations

The observations are presented as a series of images captured from eight camera locations, seven of which were video cameras and one of which was an IR camera. The camera positions inside the building are shown in Figure 3.5-2.

Figure 3.5-3 through Figure 3.5-17 present sets of eight images one from each camera position, at a given time, from the time of ignition to 28 min (1680 s) after ignition. Images were captured every 4 min and at times when events had taken place that demonstrate the experimental objectives. Each image view is labeled. The first view (BEDROOM) at the top left of each figure shows the bedroom of apartment 7K, the bedroom furthest from the apartment entrance with a view of the single window straight across, double window to the right and ignition trashcan at the foot of the bed. The top right view (LIVINGRM) was of the living room looking across to the windows. The corridor view (CORRIDOR) shows the corridor leading up to the open apartment doorway. Next to that, the outside lobby view (LOBBY) shows the area just outside the lobby doors. The next two views (STAIR and STAIR IR) show the stairwell with a visual and a thermal imaging camera from the floor below the fire looking up to the fire floor. The bottom left view (ROOF) shows the bulkhead door at the top of the stairwell and the bottom right view (OUTSIDE) shows an external view of the fire apartment.

Figure 3.5-3 shows the images at the time of ignition. At this point, the seven video views were clear and unobstructed. However, the thermal image from the stairwell provided limited thermal contrast because the surfaces in the view are at nearly equal temperature. This was the second experiment in this half of the building so there is preexisting smoke and heat damage to the corridor and stairwell. The 7$^{th}$ floor door to the stair was open at the start of the experiment.

Figure 3.5-4 shows the images at 240 s (4 min) after ignition. The bottom left window pane had just begun to fail and the wind was moving smoke and heat throughout the floor. The stair IR camera began to fail prior to this view and subsequently would provide limited information. The smoke layer throughout the fire floor had descended to the floor and was beginning to leak into the stairwell, which was closed on the 7$^{th}$ floor.

Figure 3.5-5 shows the images at 340 s (5 min and 40 s) after ignition. The bedroom window had completely failed and the 7$^{th}$ floor stair door had been opened again for 10 s. Flames were visible throughout the bedroom and moving through the living room. Visibility was lost in the corridor and stairwell. There was enough smoke being forced around the closed bulkhead door to obscure the roof camera view. Notice how flames were pulsing back out of the bedroom window against the air flow.

Figure 3.5-6 shows the images at 480 s (8 min) after ignition. The stairwell had been closed on the fire floor more than 80 s prior and the bulkhead and 1$^{st}$ floor stair A doors had been opened approximately 20 s and 70 s prior, respectively. Smoke had not cleared the stairwell; visibility in this view was still obscured. However, a significant volume of smoke was flowing from the bulkhead door. The bedroom was still full of flames and the flames continued to pulse out of the window toward the simulated wind.

Figure 3.5-7 shows the images at 550 s (9 min and 10 s) after ignition. At this time the stair door was being closed and bulkhead door was opened, allowing a flow path from the bedroom to the top of the stairwell. Visibility returned to the living room showing flames involving the sofas and floor area. Flames were flowing out of the fire apartment and out into the corridor. Smoke was thinning in the stairwell as flaming combustion was increased due to the available oxygen from the complete flow path.

Figure 3.5-8 shows the images at 585 s (9 min and 45 s) after ignition. This was captured just before deployment of the WCD over the bedroom window. Flames were still pulsing out of the bedroom window and the living room window was beginning to fail. Visibility was decreased in the living room, corridor and stairwell.

Figure 3.5-9 shows the images at 620 s (10 min and 20 s) after ignition. The WCD was deployed over the bedroom window cutting off the wind from the fire. The smoke out of the living room window had decreased and turned white.

Figure 3.5-10 shows the images at 720 s (12 min) after ignition. The burning had decreased in the bedroom and visibility was still poor in the living room and corridor. The visibility in the stairwell was improved slightly as the smoke was moving up the stairwell through the open bulkhead door.

Figure 3.5-11 shows the images at 960 s (16 min) after ignition. The bulkhead door had been closed 110 s prior and the 7$^{th}$ floor stair A door had been closed and opened approximately 220 s and 75 s prior, respectively. A PPV fan was activated at the base of the stairwell and conditions in the stairwell were improved and the cloudy view was due to soot deposited on the camera lens.

Figure 3.5-12 shows the images at 1200 s (20 min) after ignition and Figure 3.5-13 shows the images at 1440 s (24 min) after ignition. No appreciable change in conditions was visible from the video views. The stairwell remained free of smoke and there was no visible burning in the living room.

Figure 3.5-14 shows the images at 1500 s (25 min) after ignition. The living room was rekindling and flames became visible in the video view. Smoke production was increasing out of the living room window. The smoke condition in the stairwell was unchanged. This was also the time 5 s before the WCD was removed allowing the reintroduction of the simulated wind.

Figure 3.5-15 shows the images at 1560 s (26 min) after ignition. The WCD was removed 55 s prior and the wind was introduced through the window. Flames in the living room increased and were forced out of the living room windows. Smoke and heat were flowing back into the stairwell against the pressure from the fan.

Figure 3.5-16 shows the images at 1600 s (26 min and 40 s) after ignition. FBN 2 was inserted into the living room window and was flowing with a fog nozzle for 20 s at the time of this image. Large amounts of steam were seen coming from the living room. Visibility was still minimal in the living room, corridor and stairwell.

Figure 3.5-17 shows the images at 1680 s (28 min) after ignition. The view in the living room had partially returned and there were no visible flames. The conditions in the stairwell were improved and smoke flow out of the apartment visible from the outside was minimal.

Figure 3.5-3. Experiment 7K, ignition.

Figure 3.5-4. Experiment 7K, 240s after ignition.

Figure 3.5-5. Experiment 7K, 340s after ignition.

Figure 3.5-6. Experiment 7K, 480s after ignition.


**Figure 3.5-7. Experiment 7K, 550s after ignition.**


**Figure 3.5-8. Experiment 7K, 585s after ignition.**

**Figure 3.5-9. Experiment 7K, 620s after ignition.**

Figure 3.5-10. Experiment 7K, 720s after ignition.

Figure 3.5-11. Experiment 7K, 960s after ignition.


Figure 3.5-12. Experiment 7K, 1200s after ignition.


Figure 3.5-13. Experiment 7K, 1440s after ignition.

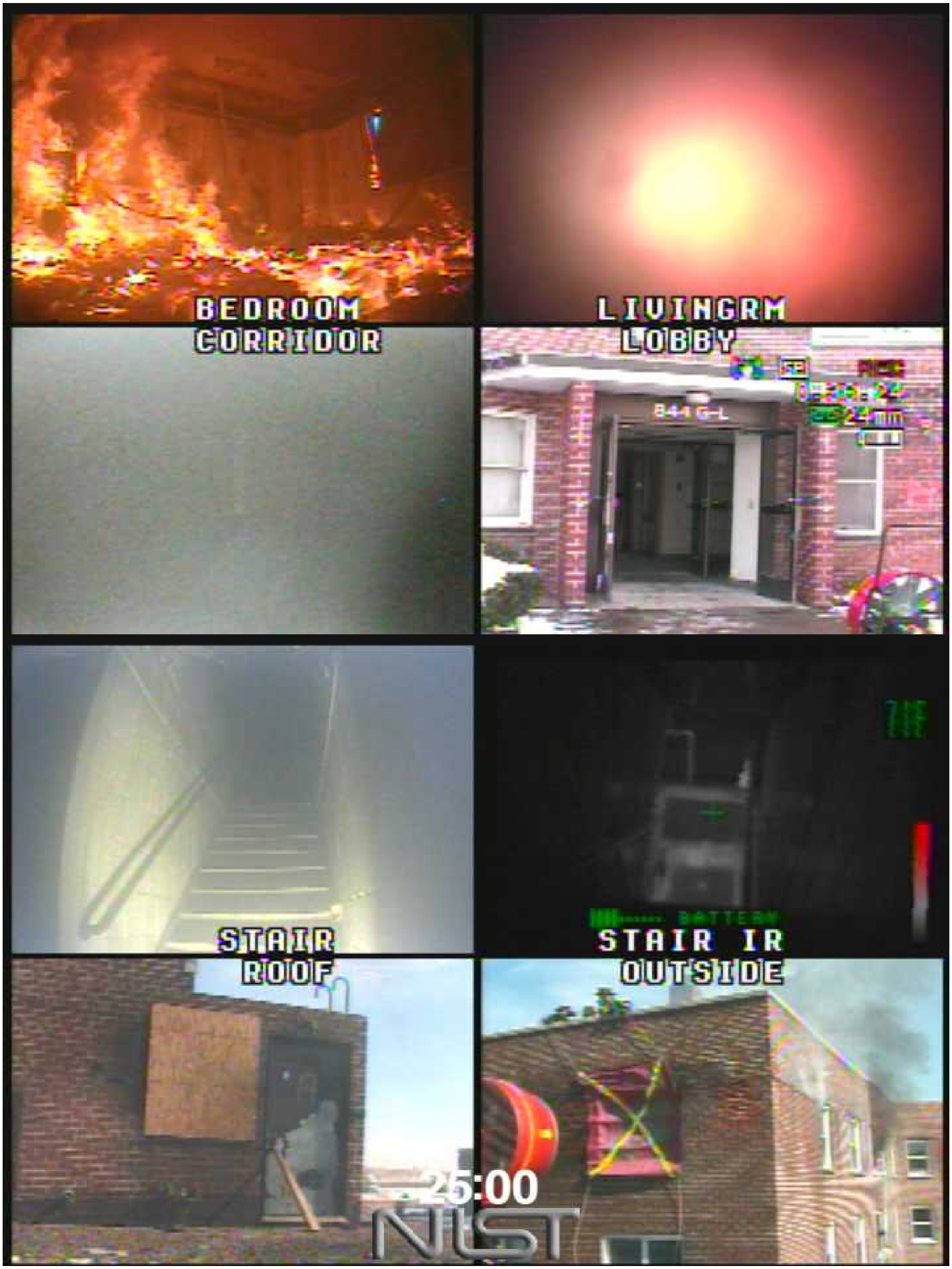


Figure 3.5-14. Experiment 7K, 1500s after ignition.

Figure 3.5-15. Experiment 7K, 1560s after ignition.

Figure 3.5-16. Experiment 7K, 1600s after ignition.


**Figure 3.5-17. Experiment 7K, 1680s after ignition.**

### 3.5.2 Temperatures

Figure 3.5-18 through Figure 3.5-20 provide temperature data for five measurement locations on the fire floor at two elevations and throughout the height of the stairwell. The locations of the measurement points can be seen in Figure 3.5-2. The events that occurred during the experiment are listed on the top of the figures with lines at the time of the event. A time history for each thermocouple at each measurement location is located in Appendix D – Detailed Graphs.

Figure 3.5-18 shows the temperatures versus time at 2.1 m (7 ft) above the floor at 4 measurement locations, just outside the fire apartment in the corridor, just outside Apartment 7G in the corridor, just outside the A stairwell doorway, and just inside the A stairwell on the landing. The bedroom 2.1 m (7 ft) thermocouple did not function correctly so the 1.8 m (6 ft) thermocouple is presented in its place. The bedroom temperature in this experiment increased to approximately 700 ºC (1292 ºF) prior to window failure and continued to increase to above 900 ºC (1652 ºF) prior to WCD deployment. After WCD deployment the temperature decreased by half to approximately 450 ºC (842 ºF) in approximately 90 s. This temperature increased again to above 600 ºC (1112 ºF) as the fire in the living room grew and increased again after the WCD was removed at 1505 s.

The temperatures just outside the fire apartment in the corridor increased quickly after the door to the stairwell on the fire floor was opened. The 2.1 m (7 ft) temperature at this location increased from approximately 300 ºC (572 ºF) to 700 ºC (1292 ºF) in less than 10 s. The wind driven condition appeared to stop and the temperatures decreased as the fire downstream became ventilation limited and the door to the 7$^{th}$ floor stairwell was closed. The bulkhead door was opened and then the 7$^{th}$ floor stair door was reopened and the temperature increased quickly again from 400 ºC (752 ºF) to 800 ºC (1472 ºF) in 10 s. The wind driven condition was reestablished and then the WCD was deployed over the bedroom window reducing the temperature in the corridor just outside the apartment from 700 ºC (1292 ºF) to less than 300 ºC (572 ºF) in 60 s. Towards the end of the experiment the WCD was removed and the fire in the living room increased to flashover. This drove the temperature up to 700 ºC (1292 ºF) and that was quickly reduced to below 200 ºC (392 ºF) within 10 s of the FBN activation.

The temperatures at the other end of the corridor near the entrance to the stairwell and Apartment 7G responded to the events similarly. This location increased to approximately 400 ºC (752 ºF) during the wind driven conditions and decreased when the door to the stairwell was closed or the WCD was in place. When the WCD was in place, stair door was opened and the PPV fan was activated the corridor temperatures reduced to ambient levels. These locations increased in temperature when the WCD was removed and the living room flashed over but quickly decreased after the FBN was activated.

The temperature at 2.1 m (7 ft) above the landing in the stairwell increased substantially when the door was opened at both 330 s and 495 s. This location's temperature increased to as high as 400 ºC (752 ºF) but decreased to less than 100 ºC (212 ºF) after the door was closed. With the WCD in place and a PPV fan operating at the base of the stairwell the temperatures in the stairwell remained ambient. When the WCD was removed and the stair was open the temperature increased to 200 ºC (392 ºF) but decreased quickly after the activation of the FBN.

Figure 3.5-19 shows the temperatures at 1.2 m (4 ft) which would be more representative to where firefighters would be operating or occupants would be evacuating. The temperature trends at this elevation are very similar to those at 2.1 m (7 ft). The temperatures responded quickly to the presence of a flow path into the stairwell. When the 7th floor stair door was opened the temperatures in the corridor rose quickly and when the stair door was closed the corridor temperatures decreased quickly. When the stair door was opened at 495 s the temperature right outside of the fire apartment increased from 300 ºC (572 ºF) to as high as 800 ºC (1472 ºF) before the door was closed. After the WCD was deployed and the door was reopened the corridor temperature did not increase at all.

The temperature on the stairwell landing at 1.2 m (4 ft) would be important because that is where the fire fighting crew would be advancing from after opening the door to the fire floor. When the door was opened this temperature increased from approximately 50 ºC (122 ºF) to over 300 ºC (572 ºF) in a matter of seconds twice in this experiment. Both times the door closing returned temperatures to less than 100 ºC (212 ºF). After the WCD was applied the stairwell door was opened and the same temperature measurement location increased from 50 ºC (122 ºF) to 100 ºC (212 ºF) which would be conducive to fire fighter advancement toward the fire apartment.

Figure 3.5-20 shows the temperatures 1.2 m (4 ft) above the landing on floors 1, 2, 4, 6 and at the landing above the 7th floor with access to the roof. The door to the fire floor was opened twice during wind driven fire conditions. Both times the temperature at the top of the stairwell increased from less than 50 ºC (122 ºF) to above 250 ºC (482 ºF) in less than 10 s. Temperatures on the sixth floor, one floor below the fire floor, saw temperature increases to above 200 ºC (392 ºF). Closing the fire floor decreased these temperatures to below 50 ºC (122 ºF). Slight temperature increases were recorded at the fourth floor which indicates that smoke made it to at least that point in the stairwell. With the WCD in place and the wind effects blocked the temperature at the top of the stairwell increased from 40 ºC (104 ºF) to 80 ºC (176 ºF) and there was no temperature increase below the fire floor.

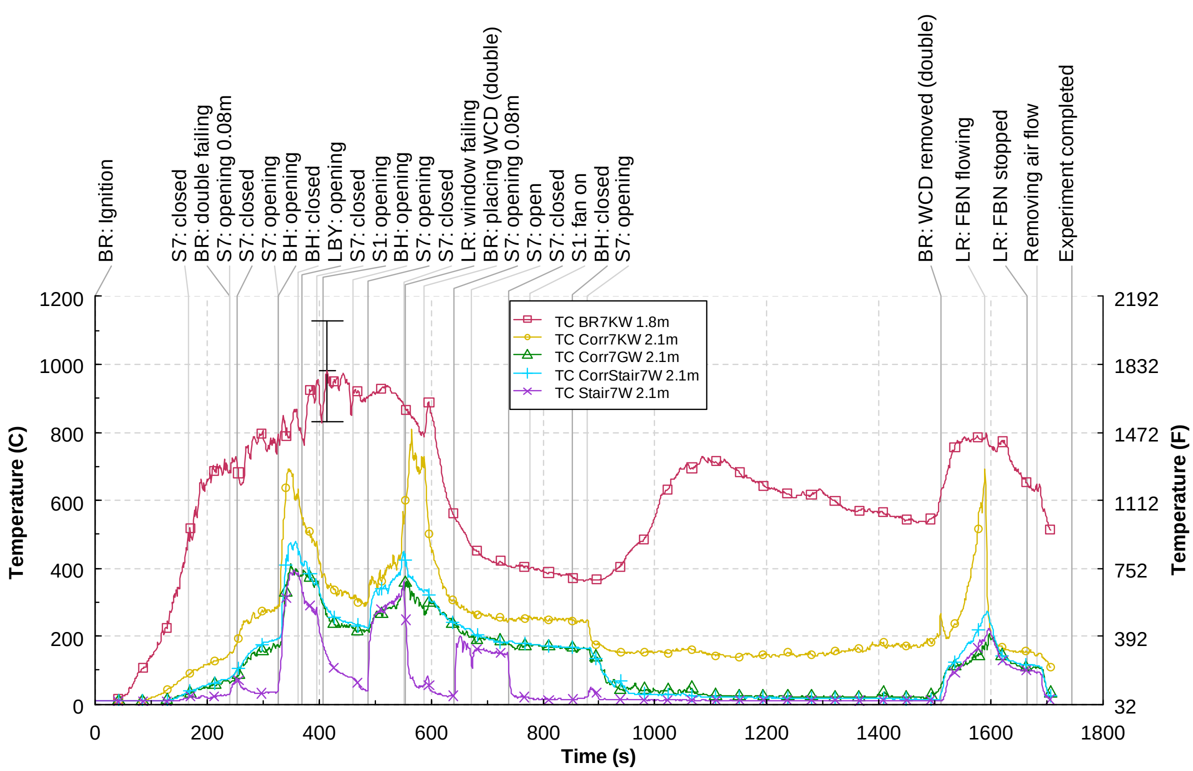



**Figure 3.5-18. 7K Temperature vs. time at 2.1 m above the floor**

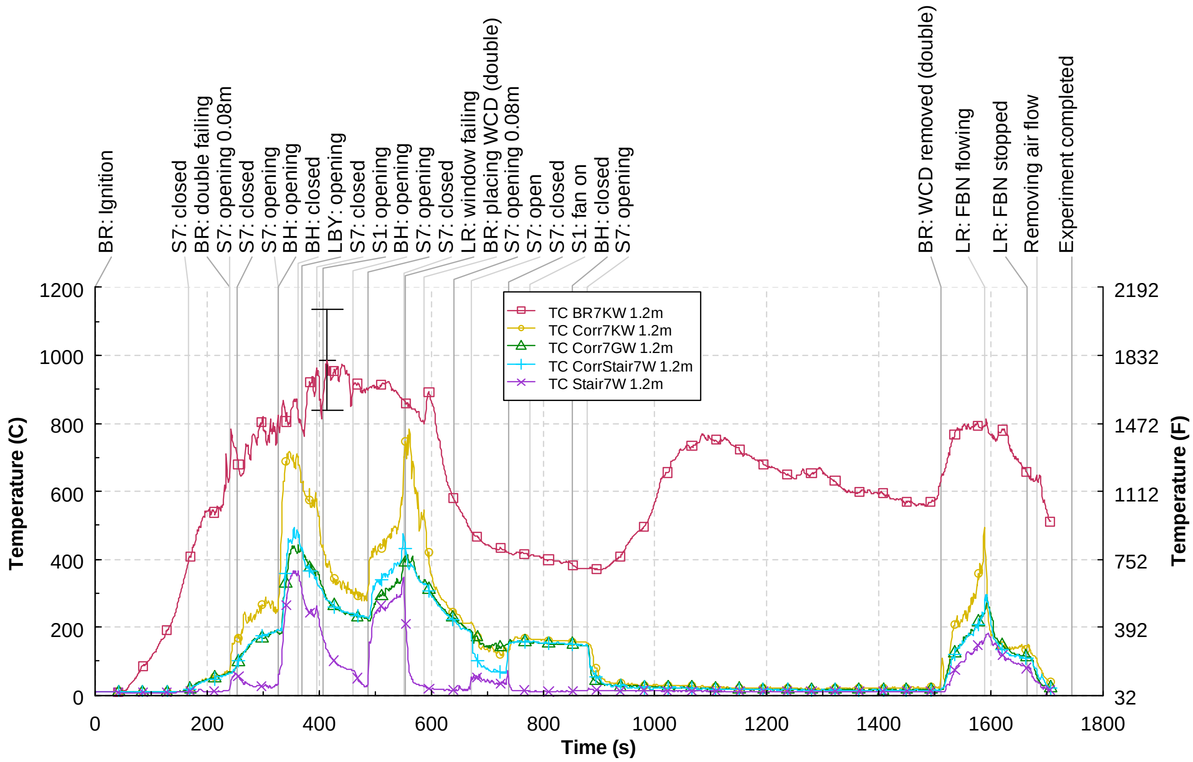



**Figure 3.5-19. 7K Temperature vs. time at 1.2 m above the floor**

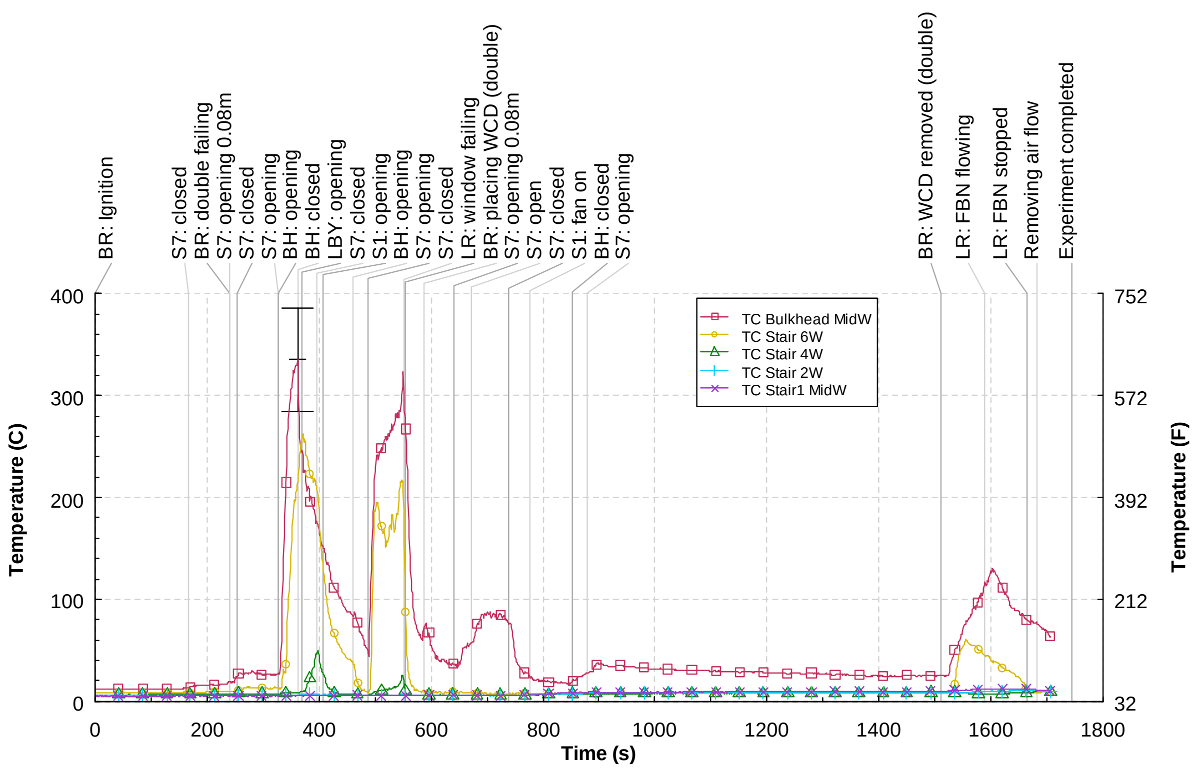



**Figure 3.5-20. 7K stairwell temperature vs. time**

### 3.5.3 Pressures

Average pressure measurements in the stairwell are shown in Figure 3.5-21. The differential pressure measurements were made at 1.2 m (4 ft) on the stairwell landing of every floor and referenced to an apartment on the same floor. With all of the doors to the stairwell closed the pressures remained below 6 Pa and only fluctuated slightly. At 240 s, shortly after the bedroom window completely failed, the stair door opened slightly then closed causing a spike in the stairwell pressure. After the stairwell door was completely opened at 330 s, and the other doors in the stairwell were closed the pressures increased 45 Pa to 75 Pa with the higher pressures at the top of the stairwell. When the fire floor stairwell door was reopened at 410 s, with the 1st floor door to the stairwell open and the bulkhead door open, the pressure in the stairwell increased 15 Pa to 25 Pa at the top of the stairwell and remained ambient below the fire floor.

Later in the experiment the stairwell was closed and a PPV fan was activated at the base of the stairwell. With the bulkhead open to ventilate the stairwell the pressures ranged from 25 Pa at the bottom to 6 Pa at the bulkhead door. The bulkhead was then closed to pressurize the stairwell and the stairwell pressure increased to approximately 25 Pa throughout. The fire floor door to the stairwell was then opened with the WCD in place and no wind impact and the pressures ranged from 25 Pa at the bottom of the stairwell to 10 Pa at the top in the area of the fire floor. Removing the WCD at 1505 s and allowing the wind to combine with the fan pressures increased the stairwell pressures to above 25 Pa throughout the stairwell.

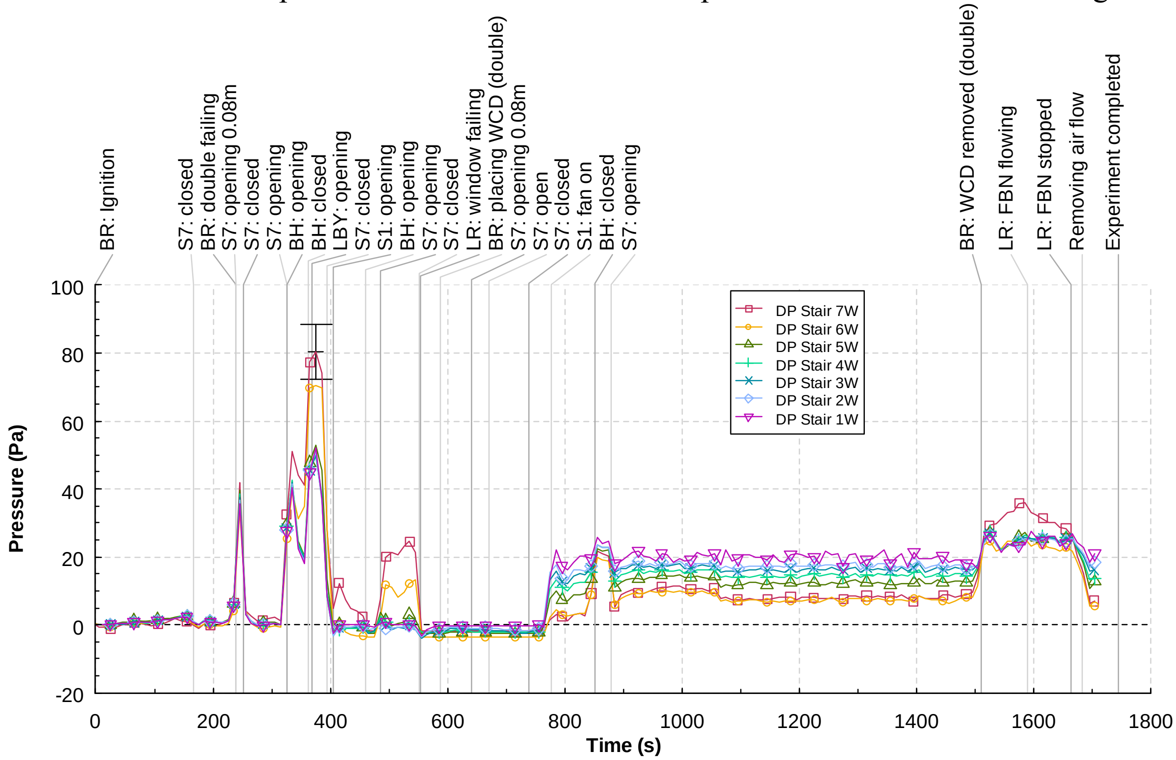



**Figure 3.5-21. 7K stairwell pressures vs. time**

### 3.5.4 Velocities

Average doorway velocities from 3 doors; the fire apartment door, the door from the fire floor to the stairwell and the door at the base of the stair, were recorded versus time and shown in Figure 3.5-22. The three bi-direction probes in each door were averaged to provide the bulk flow through the doors. A time history for each probe at each measurement location is located in Appendix D – Detailed Graphs. The velocities at the apartment doorway and stairwell doorway increase in response to the stairwell door opening and the creation of a flow path. The velocity at the apartment doorway increased from approximately 5 m/s to 17 m/s twice when the door was opened, and the stairwell door velocity increased from 2 m/s to 7 m/s twice. The flow from the fire apartment to the stairwell had to turn 180 degrees to enter the stairwell which most likely accounted for the difference in velocity between the fire apartment and the stairwell.

With the WCD in place the flow into the stairwell was decreased to approximately 1 m/s and when the PPV fan was activated and the bulkhead was closed the flow at the fire floor door was 0 m/s to 1 m/s toward the fire apartment. The bulk flow out of the fire apartment with the fan operating slowed as the fire burned down from 4 m/s down to 0 m/s before the WCD was removed. This indicates that the flow from the fan increases the pressure to stop or slow the flow into the stairwell but does not over power and drive the flow back through the fire apartment, feeding large amounts of oxygen to the fire. Fan flow does make it to the fire at the lower elevations because of lower temperatures and lower pressure differences but the impact on fire growth from this flow was not obvious in this experiment.

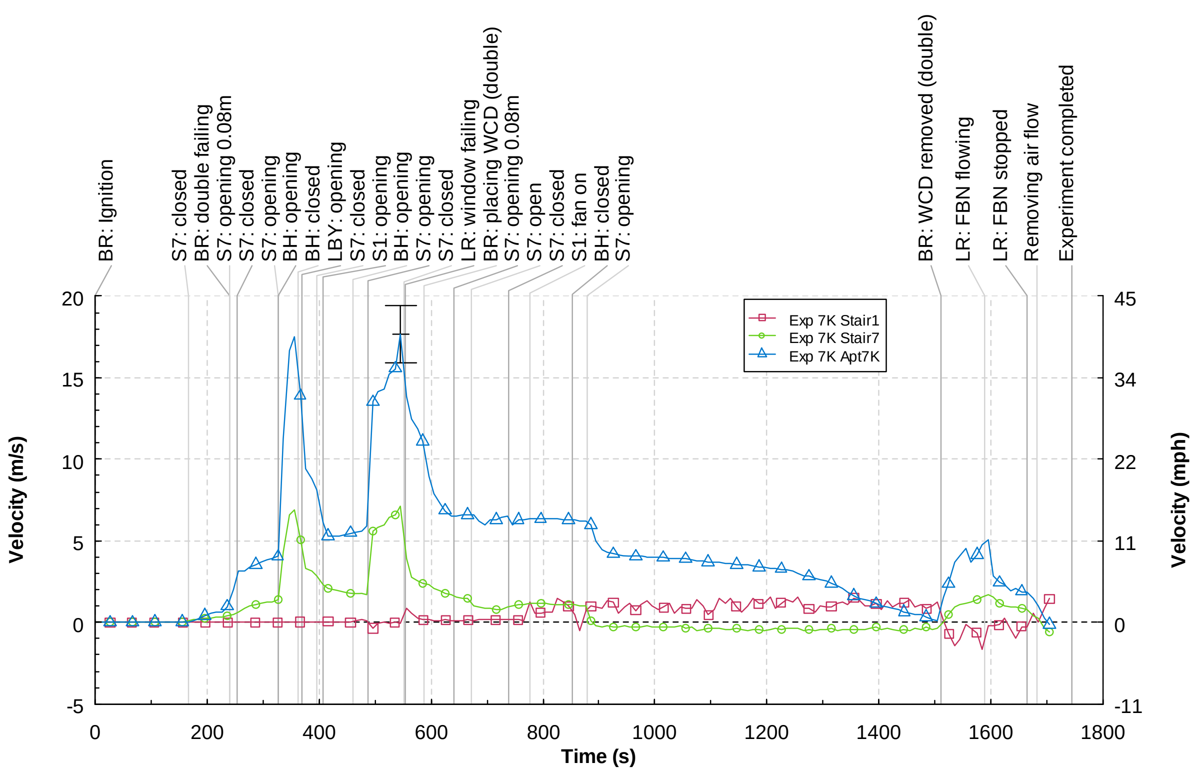



**Figure 3.5-22. 7K Velocities vs. time**

## 3.5.5 Discussion

Experiment 7K utilized the simulated wind from the MVU and created wind driven conditions on the $7^{th}$ floor. Fire gases were forced from the bedroom into the living room, igniting the living room and into the corridor and stairwell. These conditions would not be conducive to an interior direct frontal fire fighter attack. stairwell temperatures were in excess of 400 ºC (752 ºF) with the door open.

The first pane of the bedroom window failed at 180 s and the window completely failed at 224 s. The temperature in the center of the bedroom at 1.2 m (4 ft) at the time of window failure was approximately 500 ºC (932 ºF). During this experiment the fire grew rapidly prior to window failure and was not cooled by the window failure. The window failure allowed the fire to intensify immediately.

Just like the previous experiment, this experiment highlighted the importance of door control. A wind driven condition was created on the fire floor and then the stairwell door was opened. Simply opening the stairwell door caused a 300 ºC (572 ºF) to 400 ºC (752 ºF) increase in temperature throughout the fire floor and stairwell in a matter of seconds. Closing the 7th floor stair door approximately 1 minute after opening it resulted in a significant temperature decrease in both the corridor and the stairwell. Beginning with the opening of the first floor stair door at 470 s, a flow path was opened up from the bedroom through the corridor and up the stair to the bulkhead. After the 7th floor stair door and the bulkhead door open the temperatures in the corridor increased to over 700 ºC (1292 ºF), floor to ceiling.

The 7th floor stair door was closed and then 30 s later the WCD was deployed over the vented bedroom window. This resulted in a decrease in temperature in the bedroom of approximately 500 ºC (900 ºF). The temperatures downstream also decreased from approximately 700 ºC (1300 ºF) to 180 ºC (350 ºF) at 1.2 m (4 ft) above the floor in the public corridor and 7th floor stair temperatures went from in excess of 300 ºC (570 ºF) down to 50 ºC (122 ºF) at 1.2 m (4 ft) above the floor in the stair. The 7th floor stair door was opened and closed with the WCD still deployed causing an increase in temperature in the stairwell from 40 ºC (104 ºF) to 80 ºC (176 ºF). This minor increase in temperature would be conducive to a direct frontal fire attack.

The PPV fan on the 1st floor was activated at 840 s. This dropped the temperatures in the stairwell to less than 30 ºC (85 ºF). Opening the 7th floor stair door at 945 s, with the fan operating had the effect of reducing the temperatures in the corridor to ambient. While using the fan and the WCD, conditions were close to ambient for firefighters in both the corridor and the stair. The WCD was removed at 1505 s and the fire in the living room transitioned to flashover at 1515 s and the temperatures in the corridor reached over 700 ºC (1292 ºF). With the fan operating the temperatures in the corridor remained below 200 ºC (392 ºF). The fan could not stop the flow, but it limited its impact with the fire floor door open.

The removal of the WCD at 1505 seconds resulted in post-flashover conditions in the living room and an temperatures in the public hallway in excess of 700 ºC (1292 ºF). An FBN 2 with a fog nozzle, narrow pattern, flowing approximately 225 gpm of water into the living room window was put into operation at 1575 s and suppressed the fire in less than 60 s. Temperatures in the corridor and stairwell decreased to below 200 ºC (392 ºF) in seconds and continued to decrease until the experiment was ended, even with the simulated wind still flowing through the apartment.

## 3.6 Experiment 5E

The sixth experiment in the structure was located on the 5th floor in apartment 5E. Experiment 5E was ignited in the bedroom furthest from the open apartment door (Figure 3.6-1). This experiment also utilized a simulated wind provided by the MVU. The simulated wind was subjected to the bedroom double window at a magnitude of approximately 9 m/s to 11 m/s (20 mph to 25 mph). The events that took place during the experiment to accomplish the experimental objectives below are shown in Table 3.6-1.

Experimental Objectives

- Deploy WCD prior to window failure
- Examine window failure times and conditions
- Examine building flows with different door opening configurations
- Allow WCD to be subjected to fire conditions for a long period of time
- Utilize portable PPV fans to control smoke movement

The results for the experiment are presented in the following sections: observations, temperature, pressure, velocity, and discussion. Figure 3.6-2 shows the camera names and locations used in the observation section and the instrumentation names and locations used in the temperature, pressure and velocity sections.

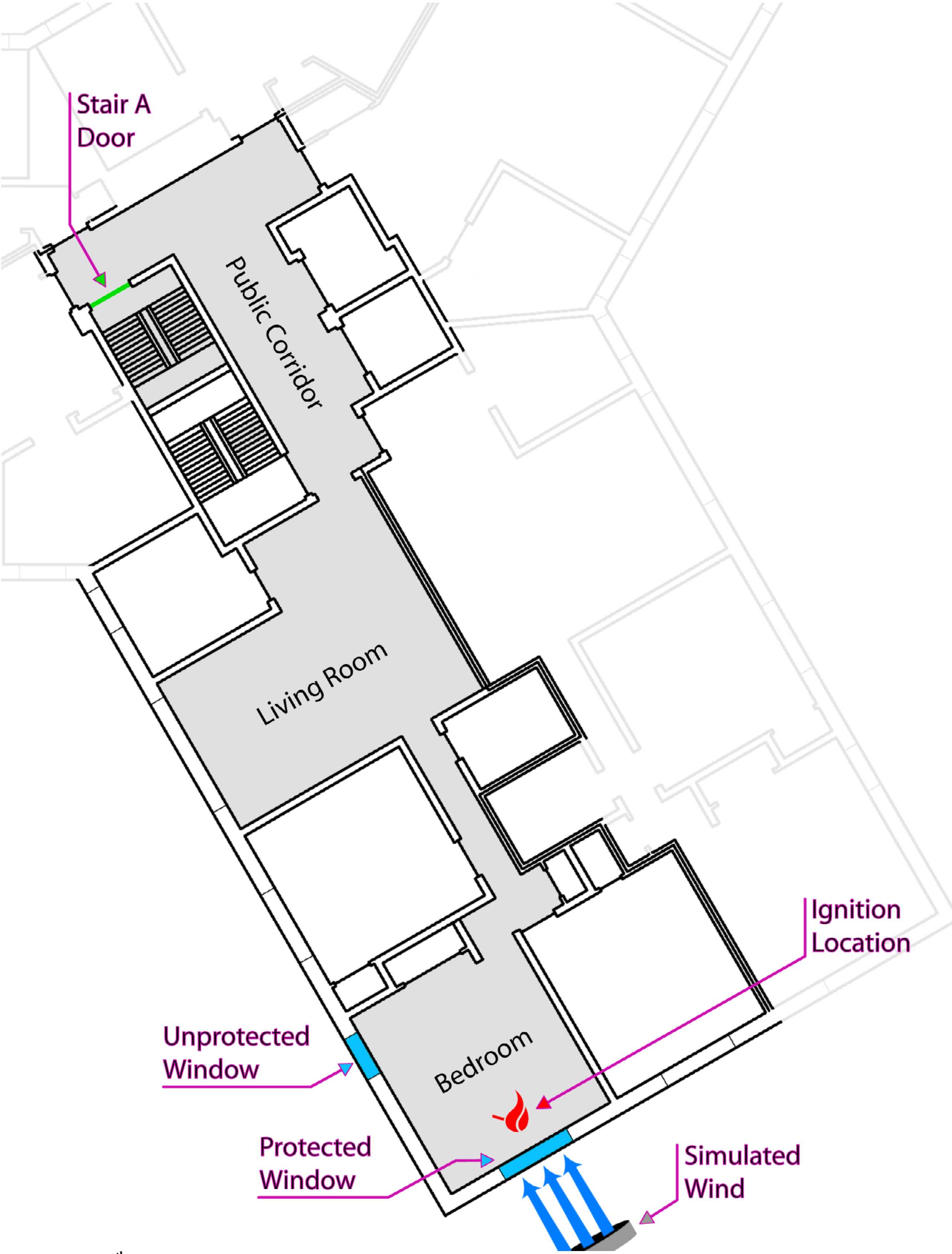



**Figure 3.6-1. 5th floor apartment E floor plan with locations pertinent to Experiment 5E**

**Table 3.6-1: Experiment 5E Timeline**

| Start (s) | End (s) | Event Location | Event Description |
|---|---|---|---|
| 0 | 0 | Bedroom | Ignition |
| 88 | 98 | Bedroom double | WCD deployed |
| 233 | 233 | Bedroom double | Protected window failing |
| 297 | 303 | 5th floor stair A | Door opened |
| 373 | 376 | Bulkhead door | Opened |
| 744 | 752 | Front lobby | Door opened |
| 752 | 758 | 1st floor stair A | Door opened |
| | 822 | Bedroom single | Cracked at top |
| 876 | 892 | 5th floor stair A | Door opened & closed 3x |
| 899 | 902 | 5th floor stair A | Door opened |
| 979 | 981 | Bedroom single | Manually vented (top pane only) |
| 1060 | 1064 | Bulkhead door | Closed |
| 1112 | 1115 | 1st floor stair A | 27 inch fan activated |
| 1308 | 1315 | Bedroom single | WCD deployed |
| 1363 | 1394 | Bedroom double | Air flow removed |
| 1380 | 1383 | 5th floor stair A | Door closed |
| 1401 | 1406 | Bulkhead door | Opened |
| 1455 | 1456 | Bulkhead door | Closed |
| 1515 | 1518 | 5th floor stair A | Door opened |
| 1619 | 1622 | 1st floor stair A | 27 inch fan deactivated |
| 1630 | 1630 | | Experiment completed |

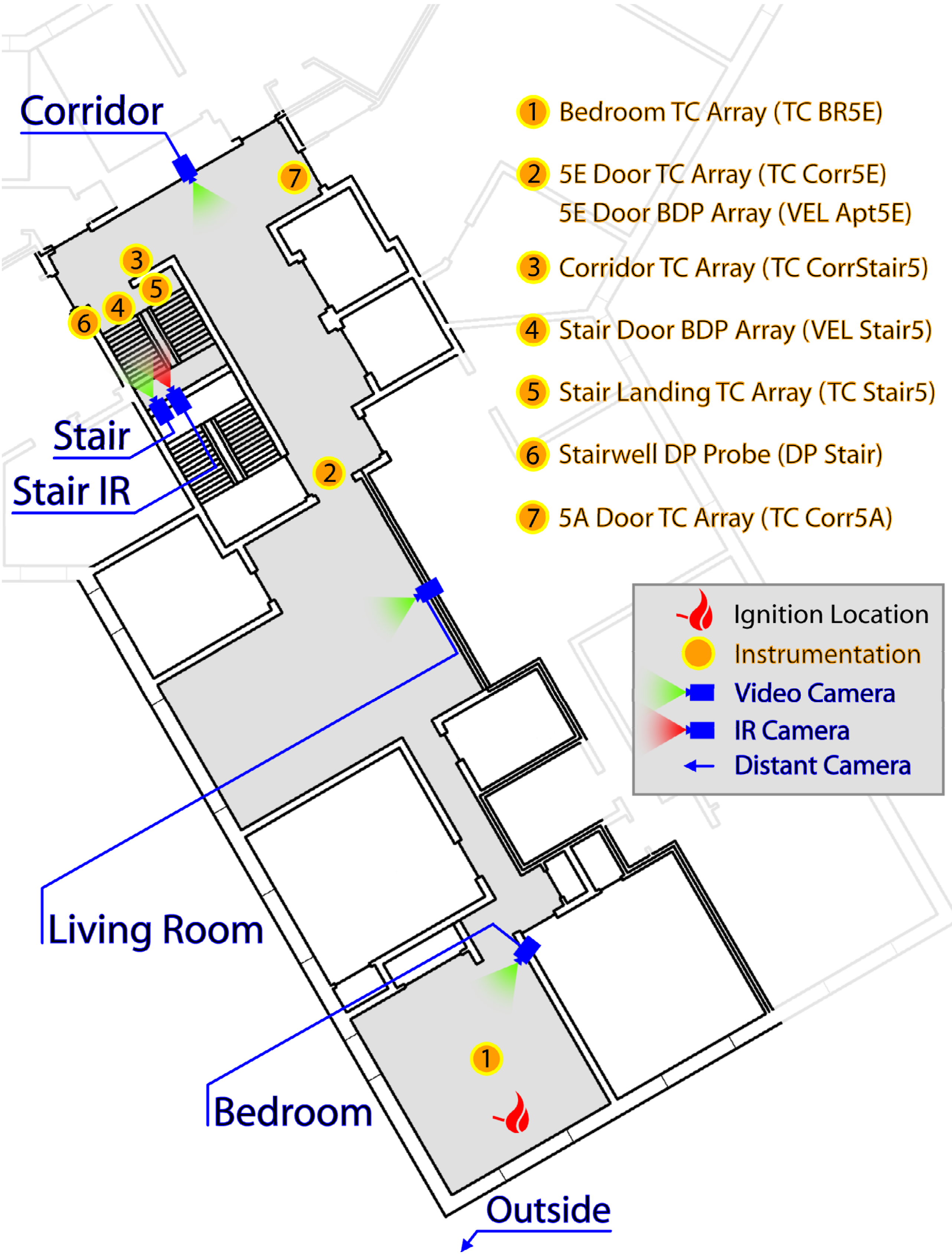



**Figure 3.6-2. Instrumentation and camera locations with labels.**

### 3.6.1 Observations

The observations are presented as a series of images captured from eight camera locations, seven were video cameras and one was a thermal imaging cameras. The camera positions inside the building are shown in Figure 3.6-2.

Figure 3.6-3 through Figure 3.6-16 present sets of eight images one from each camera position, at a given time, from the time of ignition to 44 min (2640 s) after ignition. Images were captured every 4 min and at times when events had taken place that demonstrate the experimental objectives. Each image view is labeled. The first view (BEDROOM) at the top left of each figure shows the bedroom of apartment 5E, the bedroom furthest from the apartment entrance with a view of the single window straight across, double window to the right and ignition trashcan at the foot of the bed. The top right view (LIVINGRM) was of the living room looking across to the windows. The corridor view (CORRIDOR) shows the corridor leading up to the open apartment doorway. Next to that, the outside lobby view (LOBBY) shows the area just outside the lobby doors. The next two views (STAIR and STAIR IR) show the stairwell with a visual and a thermal imaging camera from the floor below the fire looking up to the fire floor. The bottom left view (ROOF) shows the bulkhead door at the top of the stairwell and the bottom right view (OUTSIDE) shows an external view of the fire apartment.

Figure 3.6-3 shows the images at the time of ignition. At this point, the seven video views were clear and unobstructed. The thermal image in the stairwell provided limited thermal contrast because the surfaces in the view are at nearly equal temperature.

Figure 3.6-4 shows the images at 120 s (2 min) after ignition. The WCD was deployed over the double bedroom window prior to failure from fire exposure. The fire involved the area at the end of the bed where the trashcan was positioned. A smoke layer was visible throughout the fire floor at approximately 1.5 m (5 ft) above the floor.

Figure 3.6-5 shows the images at 240 s (4 min) after ignition. The window behind the WCD had just failed. At this point the smoke layer had descended to the floor in the bedroom, corridor, and living room views. Smoke had also begun to leak around the closed 5$^{th}$ floor stair A door into the stairwell.

Figure 3.6-6 shows the images at 310 s (5 min and 10 s) after ignition. The door to the stairwell was opened 7 s prior and smoke was flowing into the stairwell but was unaffected by the wind subjected to the bedroom window. Visibility was still very limited in the bedroom, living room and corridor.

Figure 3.6-7 shows the images at 395 s (6 min and 35 s) after ignition. This image shows the conditions 20 s after the bulkhead door was opened. Large amounts of smoke are visible entering the fire floor and exiting the bulkhead doorway. The smoke in the stairwell lifted from the landing of the fire floor but visibility was still minimal on the fire floor.

Figure 3.6-8 shows the images at 480 s (8 min) after ignition. Smoke was flowing up the stairwell through the open bulkhead door. Conditions had not changed significantly since the last images were recorded. Figure 3.6-9 shows the images at 720 s (12 min) after ignition. The smoke flow continued through this point with a visible decrease in smoke density in the public corridor. The thermal imaging view showed that heat flow into the stairwell was increasing. An area of discoloration formed on the WCD.

Figure 3.6-10 shows the images at 960 s (16 min) after ignition. The 5$^{th}$ floor stair A door had been open and closed several times in an attempt to fail the unprotected window in the bedroom. At this point, the smoke density on the fire floor had decreased and the view in the bedroom indicated that the fire had smothered and was not producing much smoke. The thin smoke out of the bulkhead also indicated that burning had decreased. The lobby and stair door on the first floor had also been opened approximately 200 s prior.

Figure 3.6-11 shows the images at 980 s (16 min and 20 s) after ignition. The outside view shows the unprotected window in the bedroom being manually ventilated with a pike pole from the floor above to try to give the fire more oxygen.

Figure 3.6-12 shows the images at 1200 s (20 min) after ignition. The bedroom single window had been vented manually 220 s prior and smoke was flowing out of it. Smoke density in the public corridor had further decreased as the fire apartment was drawing air from the stairwell. The flames in the bedroom had increased with the added oxygen from the ventilated window pane and open stairwell. A PPV fan was activated 85 s prior with the bulkhead door closed to pressurize the stairwell. There was still burning in the bedroom and smoke flowing from the open window pane. Smoke and heat flow into the stairwell was reduced.

Figure 3.6-13 shows the images at 1305 s (21 min and 45 s) after ignition and Figure 3.6-14 shows the images at 1320 s (22 min) after ignition. These images were captured just before and just after the second WCD was deployed over the single bedroom window that was manually ventilated.

Figure 3.6-15 shows the images at 1440 s (24 min) after ignition. A WCD had been deployed over the bedroom single window approximately 120 s prior, the 5$^{th}$ floor stair A door had been closed 57 s prior, and the bulkhead door had been open approximately 35 s prior. Smoke density in corridor, bedroom, and living room views was such that visibility was zero. The stairwell was clear of smoke, and very little smoke was venting from the open bulkhead door with the PPV fan operating.

Figure 3.6-16 shows the images at 1560 s (26 min) after ignition. At this time visibility was obscured in the living room and corridor. Ignition of all fuel surfaces in the bedroom is visible in the bedroom view. Despite the 5$^{th}$ floor stair A door being opened at 1518 s after ignition, smoke did not fill or descend the stairwell with the PPV fan operating.

Figure 3.6-3.  Experiment 5E, ignition.

**Figure 3.6-4. Experiment 5E, 120s after ignition.**


**Figure 3.6-5. Experiment 5E, 240s after ignition.**


**Figure 3.6-6. Experiment 5E, 310s after ignition.**


**Figure 3.6-7. Experiment 5E, 395s after ignition.**


**Figure 3.6-8. Experiment 5E, 480s after ignition.**

Figure 3.6-9. Experiment 5E, 720s after ignition.

Figure 3.6-10. Experiment 5E, 960s after ignition.

Figure 3.6-11.  Experiment 5E, 980s after ignition.


**Figure 3.6-12. Experiment 5E, 1200s after ignition.**

Figure 3.6-13. Experiment 5E, 1305s after ignition.

**Figure 3.6-14. Experiment 5E, 1320s after ignition.**


**Figure 3.6-15. Experiment 5E, 1440s after ignition.**

**Figure 3.6-16. Experiment 5E, 1560s after ignition.**

### 3.6.2 Temperatures

Figure 3.6-17 through Figure 3.6-19 provide temperature data for five measurement locations on the fire floor at two elevations and throughout the height of the stairwell. The locations of the measurement points can be seen in Figure 3.6-2. The events that occurred during the experiment are listed on the top of the figures with lines at the time of the event. A time history for each thermocouple at each measurement location is located in Appendix D – Detailed Graphs.

Figure 3.6-17 shows the temperatures versus time at 2.1 m (7 ft) above the floor at 5 measurement locations, the bedroom, just outside the fire apartment in the corridor, just outside Apartment 5A in the corridor, just outside the A stairwell doorway, and just inside the A stairwell on the landing. The temperature in the bedroom increased to a maximum of approximately 600 ºC (1112 ºF) before the fire became ventilation limited and the temperature declined. The temperature declined to 200 ºC (392 ºF) before responding to the added oxygen from the open stairwell and bulkhead doors. With the added oxygen and burning the temperature increased back above 600 ºC (1112 ºF). Bedroom temperatures remained around 500 ºC (1292 ºF) and increased to a peak of 800 ºC (1472 ºF) after the single bedroom window was manually ventilated and the PPV fan was activated. The temperature changes were all gradual and conditions remained ventilation limited for most of the experiment.

During the entire experiment the temperatures in the corridor, right outside the fire apartment, at 2.1 m (7 ft) above the floor do not exceed 200 ºC (392 ºF). The temperature at this position did not change significantly in response to the changes in ventilation or bedroom fire involvement and remained steady for the duration of the experiment. The two other corridor temperature measurement locations at the opposite end of the corridor remained near 100 ºC (212 ºF) for the duration of the experiment. They also remained very steady and did not change significantly in response to the changing events. The 2.1 m (7 ft) temperature in the stairwell remained ambient when the door to the fire floor was closed and increased as high as 80 ºC (176 ºF) when the door was open.

Figure 3.6-18 shows the temperatures at 1.2 m (4 ft) which would be more representative of where firefighters would be operating or occupants would be evacuating. The temperature at this elevation in the bedroom behaved very similarly to the 2.1 m (7 ft) temperature. This was consistent with a well mixed ventilation limited fire environment. These temperatures were within 100 ºC (212 ºF) for most of the experiment until about 1200 s when there was enough oxygen from the broken window to create flashover conditions in the bedroom. From that time on the bedroom temperatures were uniform throughout. All of the other 1.2 m (4 ft) temperatures on the fire floor remained at or below 100 ºC (212 ºF) for the duration of the experiment.

Figure 3.6-19 shows the temperatures 1.2 m (4 ft) above the landing on floors 1, 2, 4 and at the landing above the 7$^{th}$ floor near the bulkhead door with access to the roof. The temperature above the fire floor at the top of the stairwell was the only measurement above the fire floor and the temperature increase peaked at approximately 80 ºC (176 ºF) when the fire was at its peak. The PPV fan did not completely keep all of the smoke and heat out of the stairwell when the fire was at its peak.

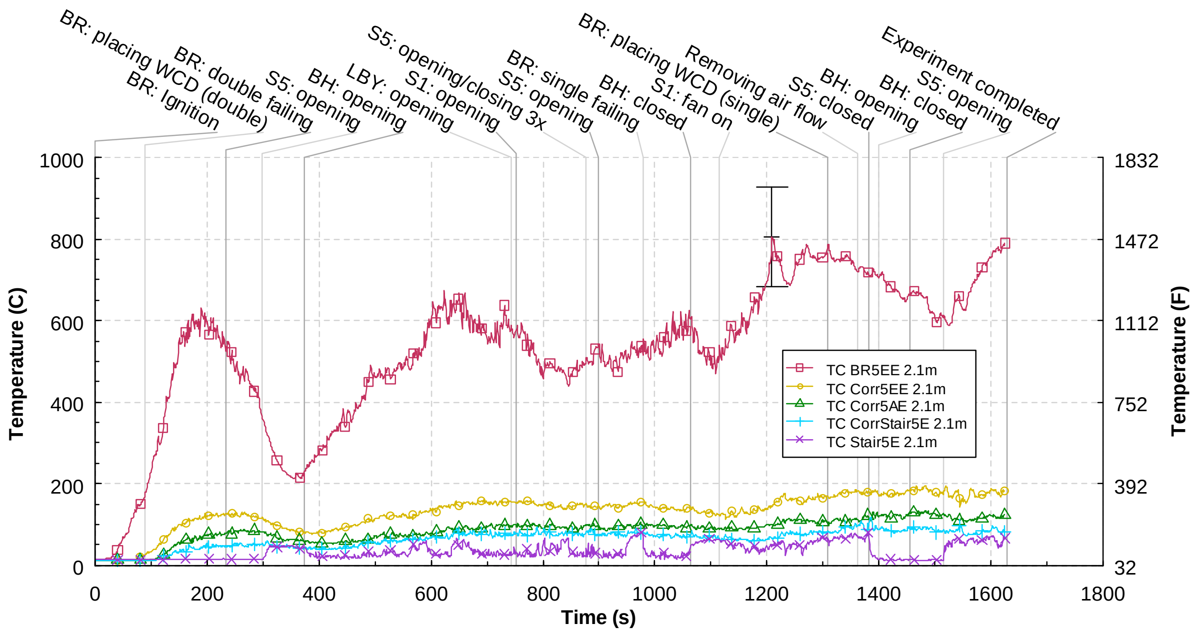



**Figure 3.6-17. 5E Temperature vs. time at 2.1 m above the floor**

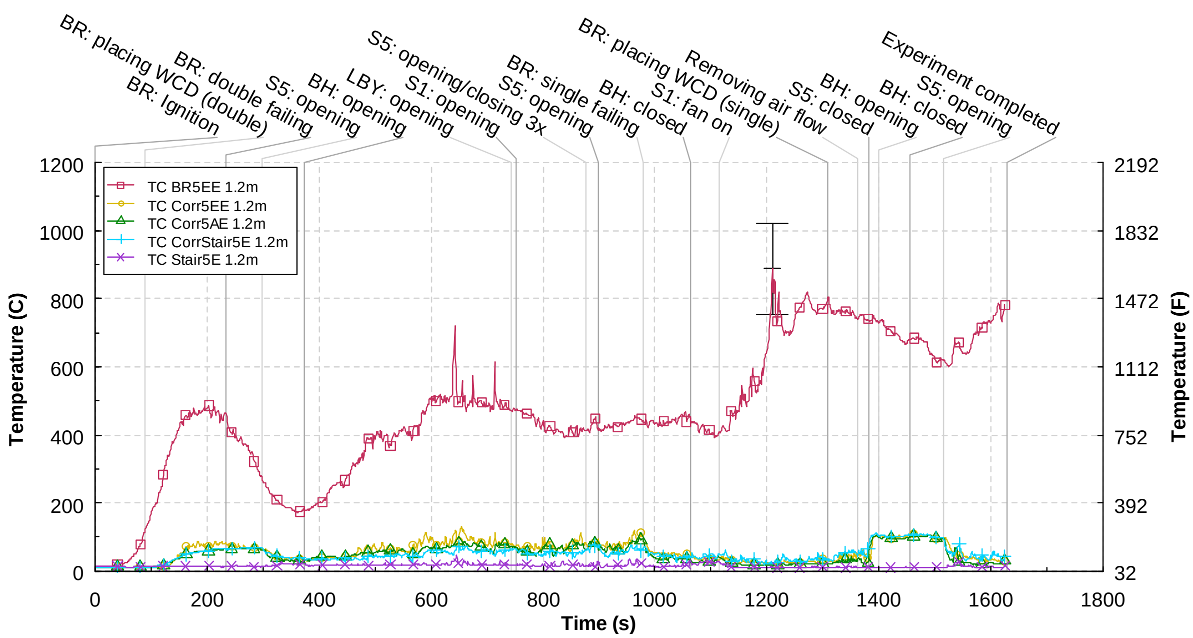



**Figure 3.6-18. 5E Temperature vs. time at 1.2 m above the floor**

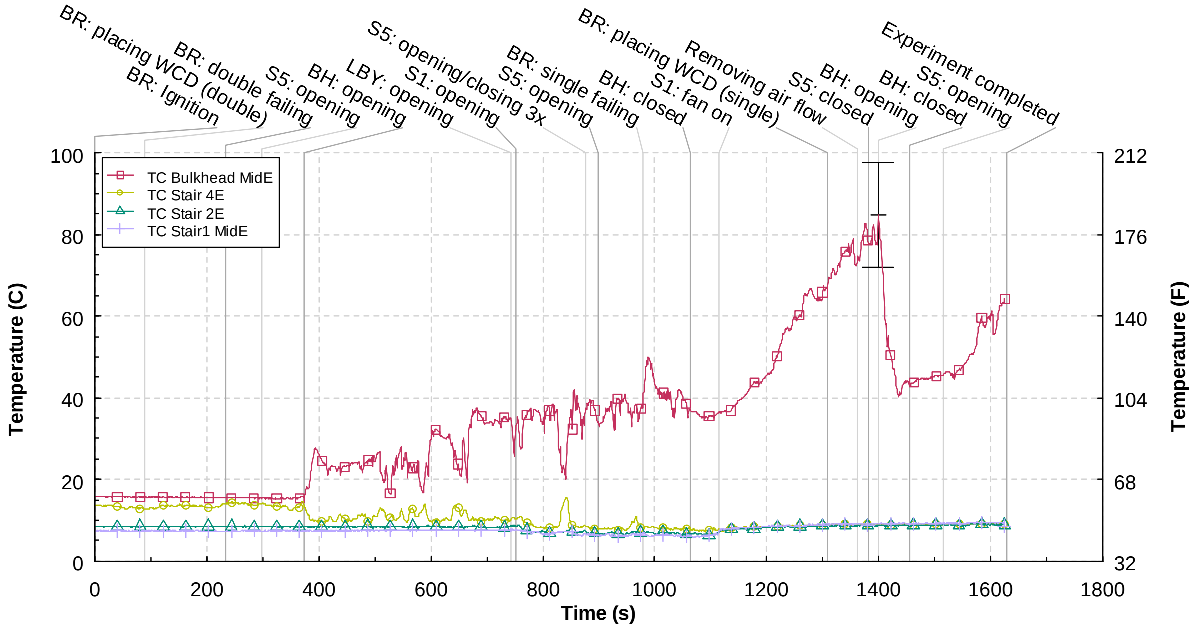



**Figure 3.6-19. 5E stairwell temperature vs. time**

## 3.6.3 Pressures

Average pressure measurements in the stairwell are shown in Figure 3.6-20. The differential pressure measurements were made at 1.2 m (4 ft) on the stairwell landing of every floor and referenced to an apartment on the same floor. With all of the doors to the stairwell closed the pressures remained below 3 Pa and only fluctuated slightly, except for the 7th floor pressure, which fluctuated around 6 Pa. This was probably due to the heat damage to the floor and the door from the experiments on the 7th floor.

Opening the bulkhead door while the first floor stairwell door remained closed lowered the pressures in the stairwell below ambient conditions. Opening the 1st floor stair door returned pressures to near ambient. The WCD was in place prior to window failure so no impact of the simulated wind was seen in the stairwell pressures. The only significant pressure increase came from the PPV fan at the base of the stairwell being activated at 1115 s. Pressures in the area of the fire floor only increased to an average of approximately 6 Pa with the bulkhead closed but decreased to 0 Pa with the bulkhead door open.

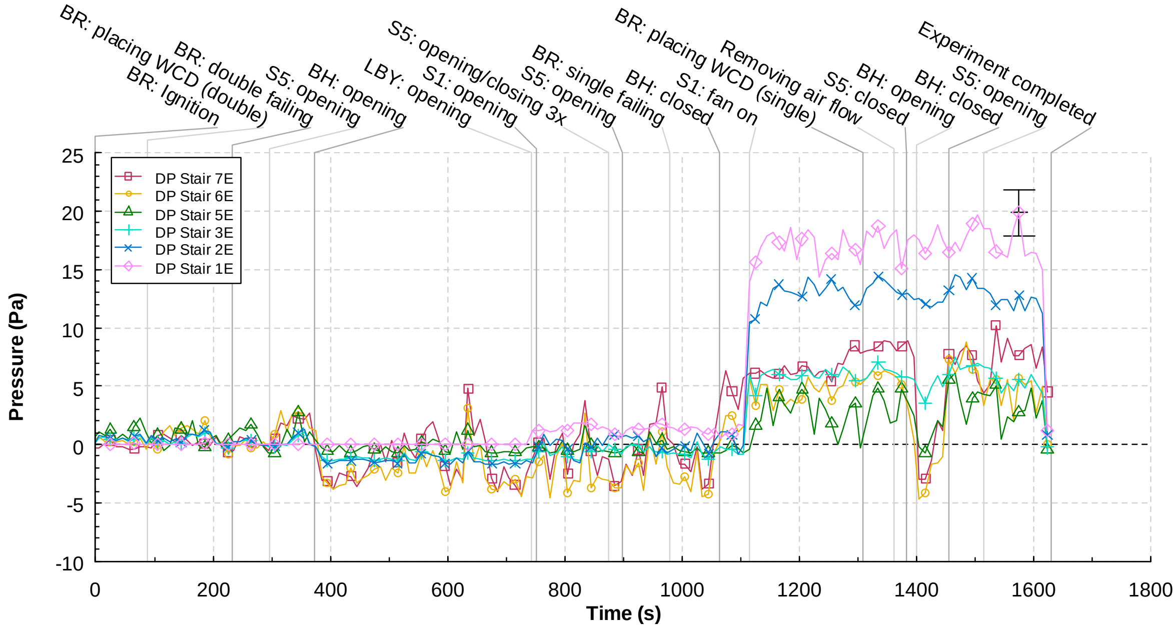



**Figure 3.6-20. 5E stairwell pressures vs. time**

### 3.6.4 Velocities

Average doorway velocities from 4 doors; the fire apartment door, the door from the fire floor to the stairwell, the door at the base of the stair and the door at the bulkhead, were recorded versus time and shown in Figure 3.6-21. The three bi-direction probes in each door were averaged to provide the bulk flow through the doors. A time history for each probe at each measurement location is located in Appendix D – Detailed Graphs.

Due to the WCD being deployed prior to window failure all measured velocities on the fire floor were less than 1 m/s (2 mph). Flow velocity out of the bulkhead door was also less than 1 m/s (2 mph). The bulk flow into the 1st floor stair door was approximately 2 m/s (4 mph) with the PPV fan operating.

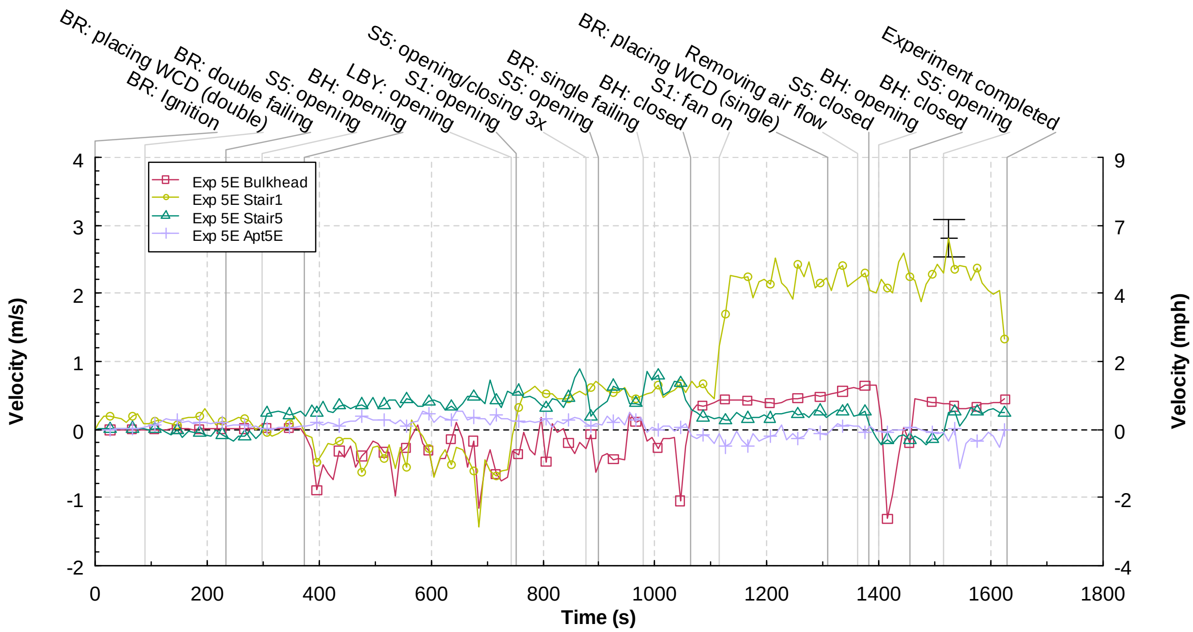



**Figure 3.6-21. 5E Velocities vs. time**

### 3.6.5 Discussion

Experiment 5E was the first experiment on the 5th floor. A WCD was deployed from the 6th floor over the bedroom double window where the simulated wind was positioned. This simulates a firefighting crew that goes to the floor above the fire and finds a wind condition subjected to that area/side of the building and the fire apartment below. As a preventative measure the crew deploys the WCD over the fire apartment window.

The window under the WCD failed at 233 s after ignition. Due to the WCD blocking the wind effects a wind driven condition was not created. The single window on the other side of the bedroom from where ignition occurred did not self-vent even after 990 s into the experiment and the fire had reached a ventilation limited, steady state condition. Temperatures at the 1.2 m (4 ft) from the floor elevation were steady around 450 ºC (842 ºF) for over 200 s. In order to increase the fire size and expose the WCD to higher temperatures the top pane of the single window in the bedroom was manually vented. This event, along with providing air from the stairwell, allowed the room to flashover and continue to burn at high temperatures for the remainder of the experiment.

Until the window in the bedroom was ventilated the only source of oxygen to the fire was from the stairwell which was remote from the bedroom. Opening the fire floor stairwell door did not provide much oxygen to the fire because the stairwell filled up with smoke quickly and mixed with any air being pulled up the stairwell. When the bulkhead door was opened this changed and the fire was able to pull fresh air as the smoke moved up and out of the stairwell. This allowed the fire in the bedroom to intensify, but because of how remote the bedroom was from the source of oxygen, the concrete walls and ceiling, and the distance to fuel through the hallway to the living room the fire did not spread. When more oxygen was provided by ventilating the top pane of the single window the fire intensified further but there was still not enough oxygen, and by that time the fuel had burned down quite a bit.

Temperatures in the corridor were not greatly impacted by ventilation and conditions were conducive to a direct frontal attack for the duration of the experiment.

Another objective of this experiment was to subject the WCD to high temperature conditions for a long period of time to see how well they would hold up. If the WCD fails during fire attack the crews being shielded from the wind driven conditions could be caught in the flow path which is not desired so the WCD must be able to withstand these conditions. While the WCD changed color from red to grey but did not fail during this experiment. Using the 1.2 m (4 ft) temperature in the center of the room to estimate the conditions the blanket was exposed to indicate that the WCD was subjected to temperatures in excess of 400 ºC (752 ºF) for more than 1100 s, including temperatures in excess of 700 ºC (1292 ºF) for at least 200 s. Flames were in contact with the WCD and there was no failure and the possible effects of a wind driven fire were never present during the experiment.

The PPV fan on the 1st floor was activated at 1115 s. This increased the pressures on the $1^{st}$ and $2^{nd}$ floors above 15 Pa as would be expected as compared to previous experiments. The pressures above this height in the stairwell were much lower than expected which suggests that stairwell doors were left open or were blown open during the experiment. This reduced the effectiveness of the fan but it still improved conditions in the area of the fire floor as seen when the fan was turned off near the end of the experiment and smoke flow into the stairwell increased. This highlights the importance of door control when utilizing PPV.

## 3.7 Experiment 5E2

The seventh experiment in the structure was located in the same apartment as the sixth experiment, 5E. Experiment 5E2 was ignited in the living room on the top of sofa that backed to the kitchen (Figure 3.7-1). The fire in the bedroom from the sixth experiment did not extend beyond the room of origin so the apartment was cleared of smoke and the experiment 5E2 was ignited. Both windows in the back bedroom failed in the previous experiment so they remained open during this experiment. This experiment also utilized a simulated wind provided by the MVU. The simulated wind was subjected to the living room window at a magnitude of approximately 9 m/s to 11 m/s (20 mph to 25 mph). The events that took place during the experiment to accomplish the experimental objectives below are shown in Table 3.7-1.

Experimental Objectives

- Create wind driven fire conditions from a living room fire
- Examine building flows with different door opening configurations
- Utilize portable PPV fans to control smoke movement
- Control wind driven conditions with FBN

The results for the experiment are presented in the following sections: observations, temperature, pressure, velocity, and discussion. Figure 3.7-2 shows the camera names and locations used in the observation section and the instrumentation names and locations used in the temperature, pressure and velocity sections.

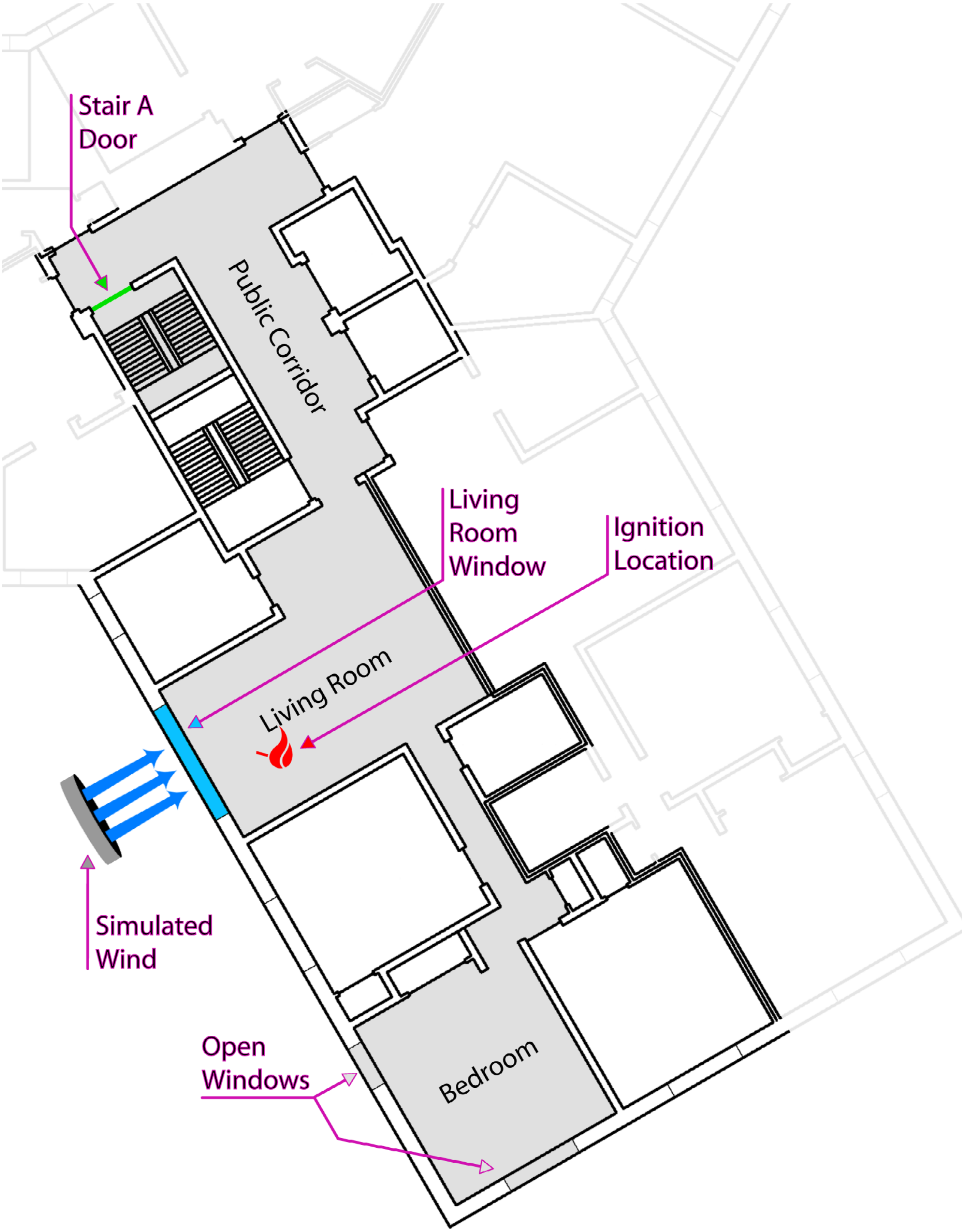



**Figure 3.7-1. 5th floor apartment E floor plan with locations pertinent to Experiment 5E2**

**Table 3.7-1: Experiment 5E2 Timeline**

| Start (s) | End (s) | Event Location | Event Description |
|---|---|---|---|
| 0 | 0 | Living room | Ignition (front doors + stair doors 1 and 5 opened) |
| 271 | 273 | Bulkhead door | Opened |
| 594 | 596 | Living room window | Center pane failed |
| 628 | 628 | Living room window | Top right pane failed |
| 681 | 681 | Living room window | Top left pane failed |
| 698 | 698 | Living room window | Bottom left pane failed |
| 716 | 719 | Bulkhead door | Closed |
| 725 | 725 | Living room | Bottom right pane failed |
| 809 | 810 | Front lobby | 27 inch fan activated |
| 837 | 841 | Front lobby | Left door closed |
| 851 | 860 | Front lobby | 27 inch fan moved, toward door |
| 880 | 883 | Front lobby | 27 inch fan moved, into door |
| 903 | 909 | Living room window | FBN 1 started flowing (Fog) |
| 915 | 920 | Front lobby | Fan moved closer to door |
| 973 | 976 | Living room window | FBN 1 stopped |
| 979 | 981 | Front lobby | Left door opened |
| 1020 | 1020 | Experiment completed | |

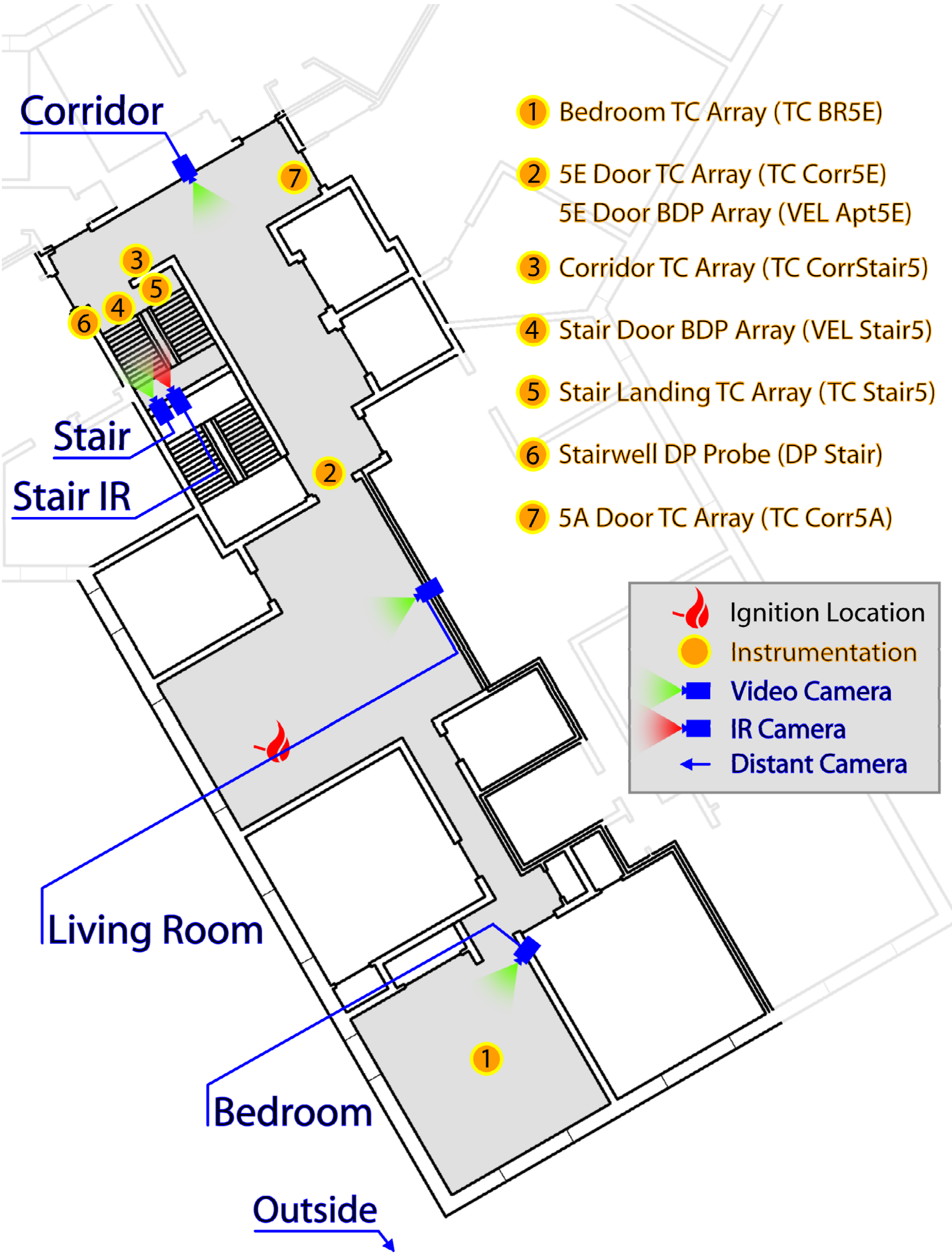



**Figure 3.7-2. Instrumentation and camera locations with labels.**

### 3.7.1 Observations

The observations are presented as a series of images captured from eight camera locations, seven were video cameras and one was a thermal imaging camera. The camera positions inside the building are shown in Figure 3.7-2.

Figure 3.7-3 through Figure 3.7-12 present sets of eight images one from each camera position, at a given time, from the time of ignition to 16 min (960 s) after ignition. Images were captured every 4 min and at times when events had taken place that demonstrate the experimental objectives. Each image view is labeled. The first view (BEDROOM) at the top left of each figure shows the bedroom which was burned in the 5E experiment, the bedroom furthest from the apartment entrance; the failed single window is straight across the view, and the failed double window is to the right of the view. The top right view (LIVINGRM) was of the living room looking across to the windows. The corridor view (CORRIDOR) shows the corridor leading up to the open apartment doorway. Next to that, the outside lobby view (LOBBY) shows the area just outside the lobby doors. The next two views (STAIR and STAIR IR) show the stairwell with a visual and a thermal imaging camera from the floor below the fire looking up to the fire floor. The bottom left view (ROOF) shows the bulkhead door at the top of the stairwell and the bottom right view (OUTSIDE) shows an external view of the fire apartment with a focus on the living room window.

Figure 3.7-3 shows the images at the time of ignition. At this point, the seven video views were clear and unobstructed. The effects of the previous experiment (experiment 5E) are visible in the corridor and bedroom views and some smoke damage from that experiment is still present in the living room. The door to the fire floor is open for the start of the experiment as seen in the stairwell views and the doors to the lobby and to the base of the stairs are open as shown in the lobby view.

Figure 3.7-4 shows the images at 240 s (4 min) after ignition. At this point, the fire that was ignited on the left sofa was growing on the seat of the sofa. Smoke density has increased in the living room, bedroom, and corridor views. Smoke is visibly flowing up the stairwell.

Figure 3.7-5 shows the images at 480 s (8 min) after ignition. The bulkhead door had been opened 208 s prior. The sofa is still not fully involved, but the smoke density throughout the apartment increased, limiting visibility in the corridor, bedroom, and living room views. The heat and volume of the smoke flow up the stairwell has increased. The fire has become ventilation limited.

Figure 3.7-6 shows the images at 660 s (11 min) after ignition. The living room window began to fail 65 s prior to these images. The added oxygen and impact of the wind has increased the fire growth and spread significantly. The living room was becoming fully involved in flames and flames were being forced through the apartment hallway and into the rear bedroom from the previous experiment. Visibility in the stairwell has been reduced and the amount of heat being forced into the stairwell has greatly increased in the thermal imaging view. The amount of smoke flowing out of the open bulkhead door has increased.

Figure 3.7-7 shows the images at 690 s (11 min and 30 s) after ignition. The living room and bedroom have become completely involved in flame and the wind driven condition has developed. Visibility has decreased to zero in the stairwell and the heat being forced up and down the stairwell has increased as indicated by the thermal imaging camera switching to its high heat mode.

Figure 3.7-8 shows the images at 720 s (12 min) after ignition. The living room window was failing incrementally; for the past 2 minutes the majority of the window opening was clear. At this point, flames were visible in the stair camera view; the stair IR view was saturated, but reflected a surface temperature in the stairwell of 260 ºC (500 ºF).

Figure 3.7-9 shows the images at 750 s (12 min and 30 s) after ignition. The bulkhead door had been closed for 30 s and the lobby image shows smoke being forced out of the front lobby doors. This shows the change in flow path and the ability to force smoke and heat down 5 stories in as little as 30 s. Both the stairwell video camera and thermal imaging camera failed due to heat exposure. Flames are no longer visible in the bedroom but are visible in the corridor. The flames are also pulsing out of the living room against the wind.

Figure 3.7-10 shows the images at 890 s (14 min and 50 s) after ignition. This was 13 s before the FBN was flowing. The wind driven condition still existed but few camera views were still usable. The living room camera still showed full room involvement.

Figure 3.7-11 shows the images at 915 s (15 min and 15 s) after ignition. This was approximately 10 s after the FBN 1 with a fog pattern was flowing into the living room. The fire was beginning to be suppressed in the living room and the flow from the nozzle can be seen in the outside view.

Figure 3.7-12 shows the images at 960 s (16 min) after ignition. At this point FBN 1 had been flowing into the living room window for almost 60 s. The fire appears to be limited to some of the furnishings. The burning, hot gas layer had been extinguished. Most of the other cameras were either non-operational or obstructed by soot deposition.

Figure 3.7-3. Experiment 5E2, ignition.

**Figure 3.7-4. Experiment 5E2, 240s after ignition.**

Figure 3.7-5. Experiment 5E2, 480s after ignition.


**Figure 3.7-6. Experiment 5E2, 660s after ignition.**


**Figure 3.7-7. Experiment 5E2, 690s after ignition.**

Figure 3.7-8. Experiment 5E2, 720s after ignition.

Figure 3.7-9. Experiment 5E2, 750s after ignition.


**Figure 3.7-10. Experiment 5E2, 890s after ignition.**

Figure 3.7-11. Experiment 5E2, 915s after ignition.

Figure 3.7-12. Experiment 5E2, 960s after ignition.

### 3.7.2 Temperatures

Figure 3.7-13 through Figure 3.7-15 provide temperature data for four measurement locations on the fire floor at two elevations and throughout the height of the stairwell. The locations of the measurement points can be seen in Figure 3.7-2. The events that occurred during the experiment are listed on the top of the figures with lines at the time of the event. A time history for each thermocouple at each measurement location is located in Appendix D – Detailed Graphs.

Figure 3.7-13 shows the temperatures versus time at 2.1 m (7 ft) above the floor at 4 measurement locations, just outside the fire apartment in the corridor, just outside Apartment 5A in the corridor, just outside the A stairwell doorway, and just inside the A stairwell on the landing. The bedroom measurement location was compromised during the previous experiment and is not included in this analysis. There were no temperature measurements in the living room, so the closest measurement to the fire was the corridor just outside the fire apartment. The fire reached a steady state with the corridor temperature at approximately 150 ºC (302 ºF) as the smoke layer descended to the height of the seat of the sofa. The bulkhead door was opened to provide oxygen and the temperature steadily increased to approximately 300 ºC (572 ºF), while the fire on the sofa increased. The increased fire size caused the window to begin to fail and the conditions changed rapidly. The temperature at 2.1 m (7 ft) cooled briefly as the cold air was forced into the living room but once conditions changed the temperature increased from less than 300 ºC (572 ºF) to more than 800 ºC (1472 ºF) in seconds. The bulkhead door was closed to change the flow path and the temperature steadily decreased from 900 ºC (1652 ºF) to 450 ºC (842 ºF) over the next 200 s. At 903 s the FBN was activated and the temperature dropped to approximately 150 ºC (302 ºF) in the 70 s the nozzle was flowing.

The two other corridor measurement locations responded similarly to the events as the one closest to the fire apartment, except their peak temperatures were lower. The measurement location in the corridor next to the open stairwell door reached 800 ºC (1472 ºF) and the measurement location next to Apartment A reached 600 ºC (1112 ºF). This temperature difference also shows the difference in temperature between being in the flow path and being just outside the flow path. The temperature of the corridor after the nozzle had been flowed for 70 s was conducive to a direct frontal fire attack.

The temperature in the stairwell also reached 600 ºC (1112 ºF) at the peak of the wind driven condition. Once the bulkhead door was closed the temperature steadily decreased to approximately 300 ºC (572 ºF) before the FBN was flowing. After the FBN was flowing the temperature decreased to 150 ºC (302 ºF).

Figure 3.7-14 shows the temperatures at 1.2 m (4 ft) which would be more representative to where firefighters would be operating or occupants would be evacuating. The temperatures at all of the measurement locations at the 1.2 m (4 ft) elevation remained below 50 ºC (122 ºF) as the fire was developing in the living room. At approximately 550 s the living room was transitioning to flashover and the temperatures increased to as high as 250 ºC (482 ºF) in the corridor as the window failed. The temperatures increased as the fresh air was mixing in the living room. At approximately 675 s the flow path from the living room to the stairwell was well mixed and the temperatures were the same as the 2.1 m (7 ft) elevation showing that there was no longer a cool layer and the temperatures were increasing from floor to ceiling. After the FBN was flowed the temperatures decreased to approximately 100 ºC (212 ºF) which would allow fire fighters to advance to the fire apartment.

Figure 3.7-15 shows the temperatures 1.2 m (4 ft) above the landing on floors 1, 2, 4 and at the bulkhead. The temperature at the top of the stairwell started the experiment elevated from the hot gases trapped in the top of the stairwell from the previous experiment. During the wind driven condition with the bulkhead door open temperatures above the fire floor reached as high as 1200 ºC (2192 ºF) and decreased quickly when the bulkhead door was closed because this area was no longer part of the flow path. During the wind driven condition temperatures below the fire floor on the 4th floor reached 400 ºC (752 ºF) and the 2nd floor temperature was above 150 ºC (302 ºF). After suppression was started with the FBN the temperature below the fire floor decreased to below 100 ºC (212 ºF).

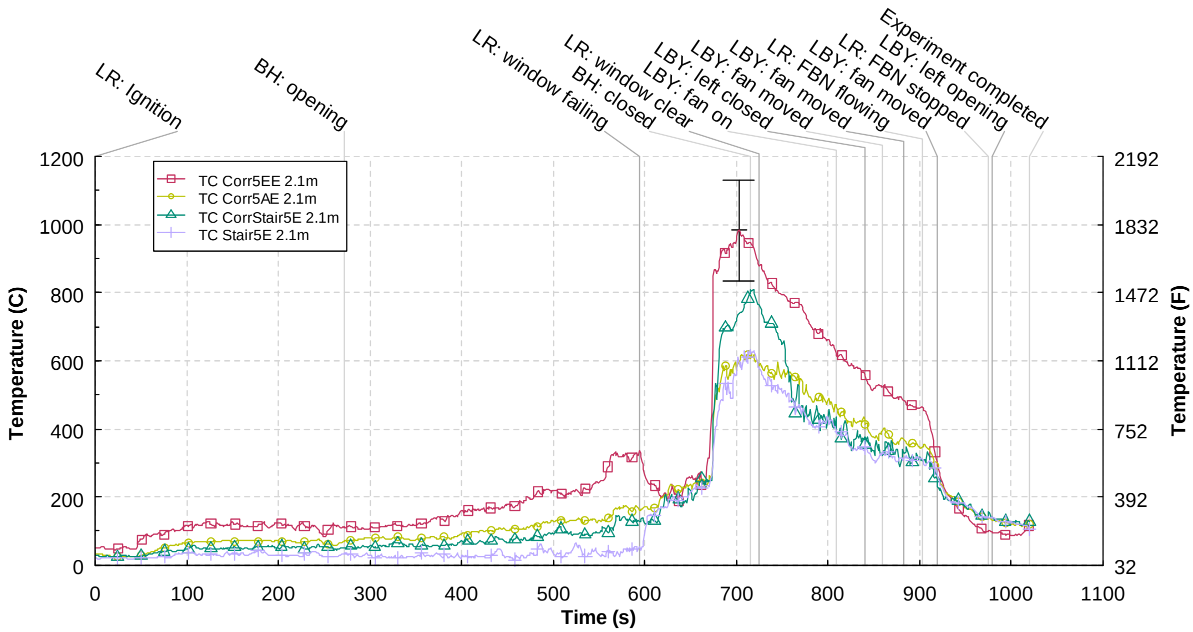



**Figure 3.7-13. 5E2 Temperature vs. time at 2.1 m above the floor**

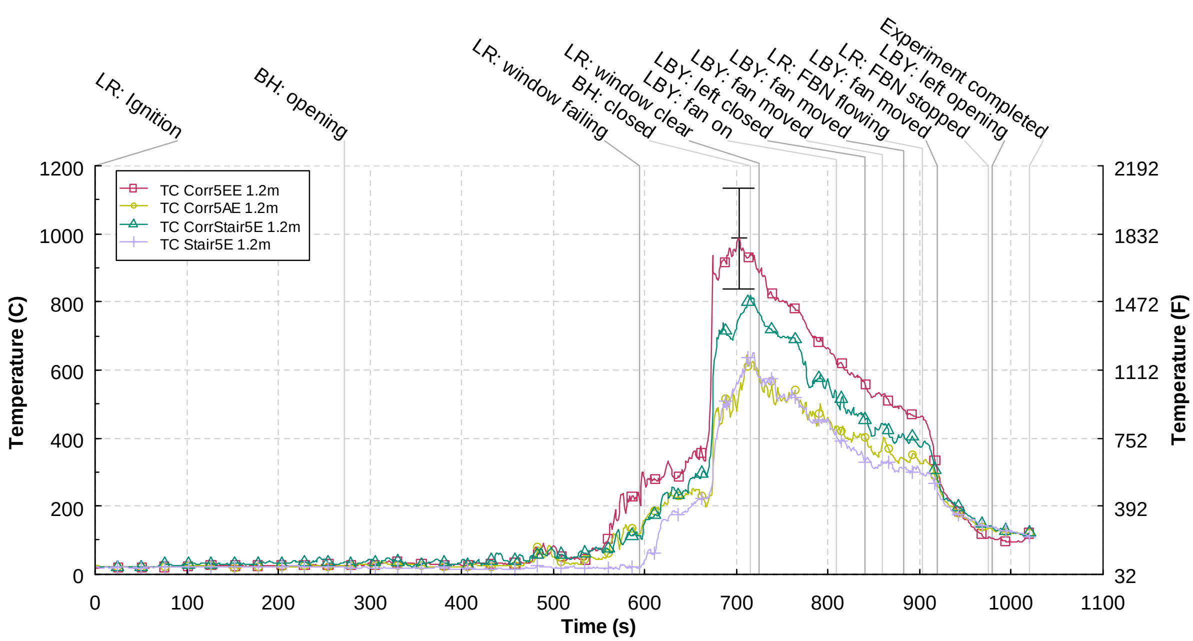


**Figure 3.7-14.  5E2 Temperature vs. time at 1.2 m above the floor**

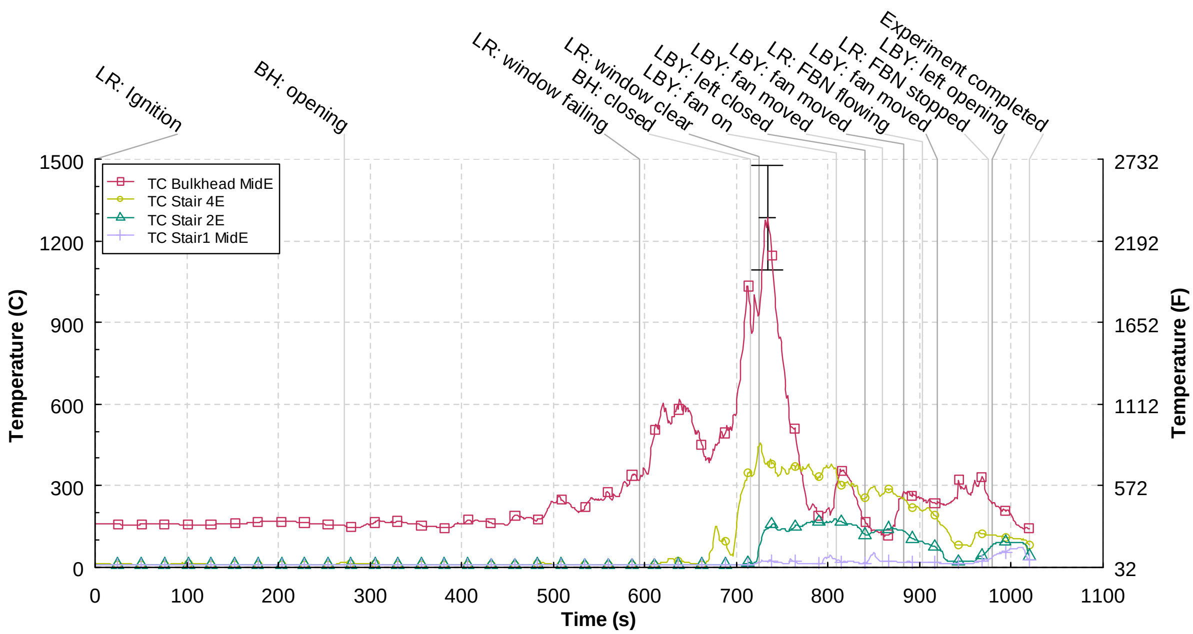



**Figure 3.7-15.  5E2  stairwell temperature vs. time**

### 3.7.3 Pressures

Average pressure measurements in the stairwell are shown in Figure 3.7-16.  The differential pressure measurements were made at 1.2 m (4 ft) on the stairwell landing of every floor and referenced to an apartment on the same floor.  With all of the doors to the stairwell closed the pressures remained below 5 Pa and only fluctuated slightly, except for the 7$^{th}$ floor pressure which fluctuated around 8 Pa.  This was most likely due to the heat accumulation in the top of the stairwell in the area of the 7$^{th}$ floor.

The pressures all remained constant until the windows in the living room began to fail.  After window failure the pressures in the stairwell in the area of the fire floor increased to approximately 5 Pa.  This minimal impact was due to the top and bottom of the stairwell being open.  When the bulkhead door was closed the pressure increased quickly.  The 7$^{th}$ floor increased from less than 10 Pa to more than 80 Pa in seconds.  The other floors from the 6$^{th}$ to the 2$^{nd}$ increased to approximately 70 Pa, 65 Pa, 50 Pa, 35 Pa and 20 Pa respectively.

Adding the PPV fan at the front lobby door at 810 s increased the lower floor pressures.  As it was moved closer to the stairwell when the smoke flow out of the front of the building decreased the pressures increased.  Flowing the FBN and stopping the wind driven fire condition caused the pressures in the stairwell to decrease with the decreased energy production from the fire.

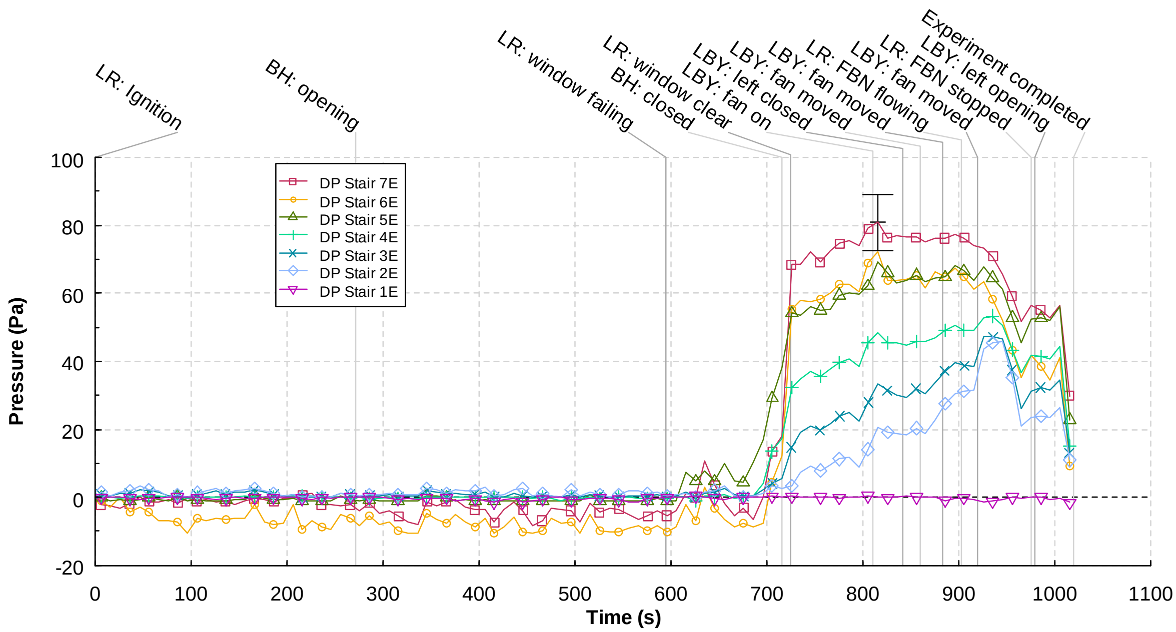



**Figure 3.7-16. 5E2 stairwell pressures vs. time**

### 3.7.4 Velocities

Average doorway velocities from 4 doors; the fire apartment door, the door from the fire floor to the stairwell, the door at the base of the stair and the door at the bulkhead, were recorded versus time and shown in Figure 3.7-17. The three bi-direction probes in each door were averaged to provide the bulk flow through the doors. A time history for each probe at each measurement location is located in Appendix D – Detailed Graphs.

The fire floor stairwell door remained open for the duration of the experiment enabling a flow path to the stairwell. The velocity at the apartment doorway increased in response to the growth of the living room fire and increased further once the window failed. The velocity increased to a peak of approximately 9 m/s (20 mph) before the bulkhead door was closed. The flow from the fire apartment had to turn 180 degrees to enter the stairwell which most likely accounted for the difference in velocity between the fire apartment and the stairwell. The flow through the bulkhead door was very similar to the flow leaving the fire apartment as would be expected but the velocity measurement beyond 650 s was not reliable because of the extreme heat the pressure transducers were subjected too.

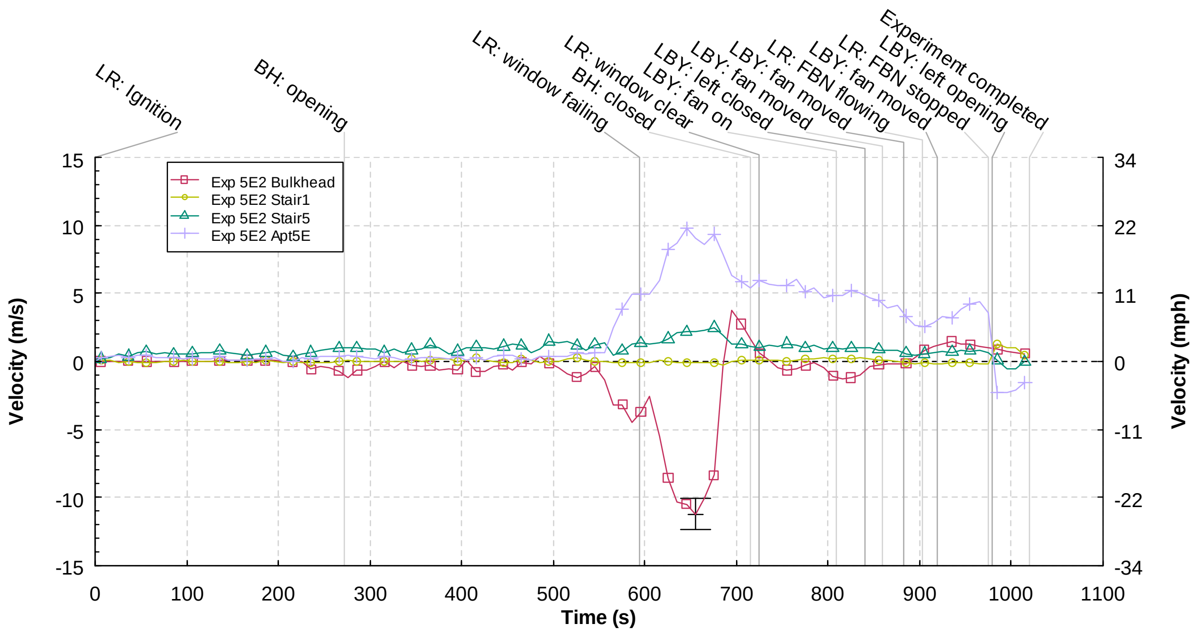



**Figure 3.7-17. 5E2 Velocities vs. time**

### 3.7.5 Discussion

This experiment utilized the simulated wind directed into the living room and a wind driven condition was created which caused extremely hazardous conditions inside the building. Temperatures exceeded 600 ºC (1112 ºF) throughout the fire floor at any elevation above the floor. These same temperatures entered the stairwell extended to the top of the stairwell and created poor conditions down the stairwell and into the lobby. Large amounts of smoke were forced out of the front lobby door displaying untenable conditions throughout the entire stairwell. The condition created during this experiment were not conducive to a direct frontal fire attack and firefighters remote from the fire in the stairwell would have been threatened if they were in the flow path due to extreme temperatures.

The fire became ventilation limited and was beginning to burn itself out, even with the windows open in the bedroom from the previous experiment. The bulkhead door was opened and that allowed the smoke layer to move up the stairwell and create a condition for the fire to grow. The fire transitioned to flashover and failed the window which triggered the wind driven condition. The hot gases were primarily being forced to the stairwell and up the stairs to the open bulkhead door. Once the bulkhead door was closed the conditions changed. The flow was forced to travel down the stairs to the front door but did so slowly. Without the smoke moving upward the wind driven fire in the corridor became ventilation limited and the temperatures in the corridor and stairwell decreased by nearly half. This scenario also had the fire floor stairwell door open the entire experiment. This door is a key door to limit the impact to the rest of the structure. With this door open other floors were exposed to untenable conditions for firefighters and occupants.

A FBN 1 with a fog nozzle, narrow pattern, flowing approximately 10.1 L/s (160 gpm) of water into the living room window was put into operation at 903 s and was allowed to flow for about 70s. Temperatures in the corridor and stairwell decreased to below 200 ºC (392 ºF) very quickly and continued to decrease until the experiment was ended, even with the simulated wind still flowing through the apartment. The water introduced to the seat of the fire changed an environment with burning gases to just burning objects. The fire was not able to be extinguished completely with the FBN, but it reduced its energy output significantly.

## 3.8 Experiment 5K

The eighth experiment was located on the 5th floor in apartment 5K. Experiment 5K was ignited in the bedroom furthest from the open apartment door (Figure 3.8-1). This experiment also utilized a simulated wind provided by the MVU. The simulated wind was subjected to the bedroom double window at a magnitude of approximately 9 m/s to 11 m/s (20 mph to 25 mph). The events that took place during the experiment to accomplish the experimental objectives bulleted below are shown in Table 3.8-1.

Experimental Objectives

- Create wind driven fire conditions from a bedroom fire
- Examine window failure times and conditions
- Examine building flows with different door opening configurations
- Examine impact of the partial deployment of a WCD on fire room window
- Control wind driven conditions with FBN in conjunction with WCD
- Utilize portable PPV fans to control smoke movement

The results for the experiment are presented in the following sections: observations, temperature, pressure, velocity, and discussion. Figure 3.8-2 shows the camera names and locations used in the observation section and the instrumentation names and locations used in the temperature, pressure and velocity sections.

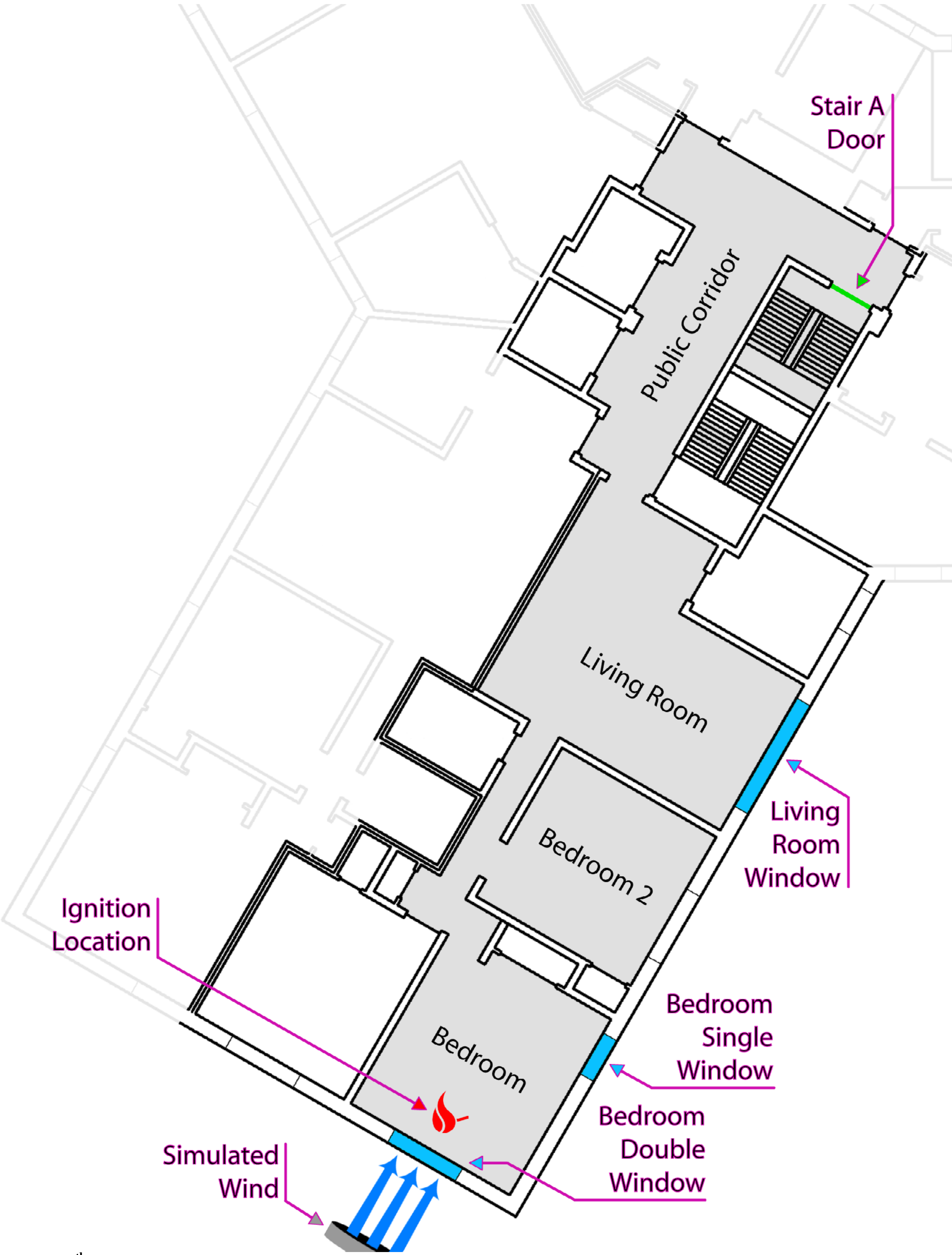



**Figure 3.8-1. 5th floor apartment K floor plan with locations pertinent to Experiment 5K**

**Table 3.8-1: Experiment 5K Timeline**

| Start (s) | End (s) | Event Location | Event Description |
|---|---|---|---|
| 0 | 0 | Bedroom | Ignition |
| 303 | 304 | Bedroom double | Bottom left pane failed |
| 452 | 468 | 5th floor stair A | Door opened |
| 487 | 494 | Front lobby | Doors opened |
| 513 | 518 | 1st floor stair A | Door opened |
| 693 | 695 | Bedroom double | Bottom right pane failed |
| 696 | 700 | Bulkhead door | Opened |
| 798 | 798 | Bedroom double | Top left pane failed |
| 830 | 831 | Bedroom double | Top right pane failed |
| 953 | 975 | Bedroom double | WCD deploying (1/2 of window) |
| 1012 | 1012 | Living room window | Starting to fail |
| 1043 | 1045 | Bedroom double | FBN 1 started flowing (Fog) |
| 1124 | 1124 | Bedroom double | FBN 1 stopped |
| 1180 | 1184 | Bulkhead door | Closed |
| 1219 | 1219 | Living room window | FBN 1 started flowing (Fog) |
| 1295 | 1295 | Living room window | FBN 1 stopped |
| 1456 | 1464 | 1st floor stair A | 27 inch fan activated |
| 1501 | 1503 | Bulkhead door | Opened |
| 1590 | 1592 | Bulkhead door | Closed |
| 1873 | 1885 | Bedroom double | Air flow removed |
| 1920 | 1920 | Experiment completed | |

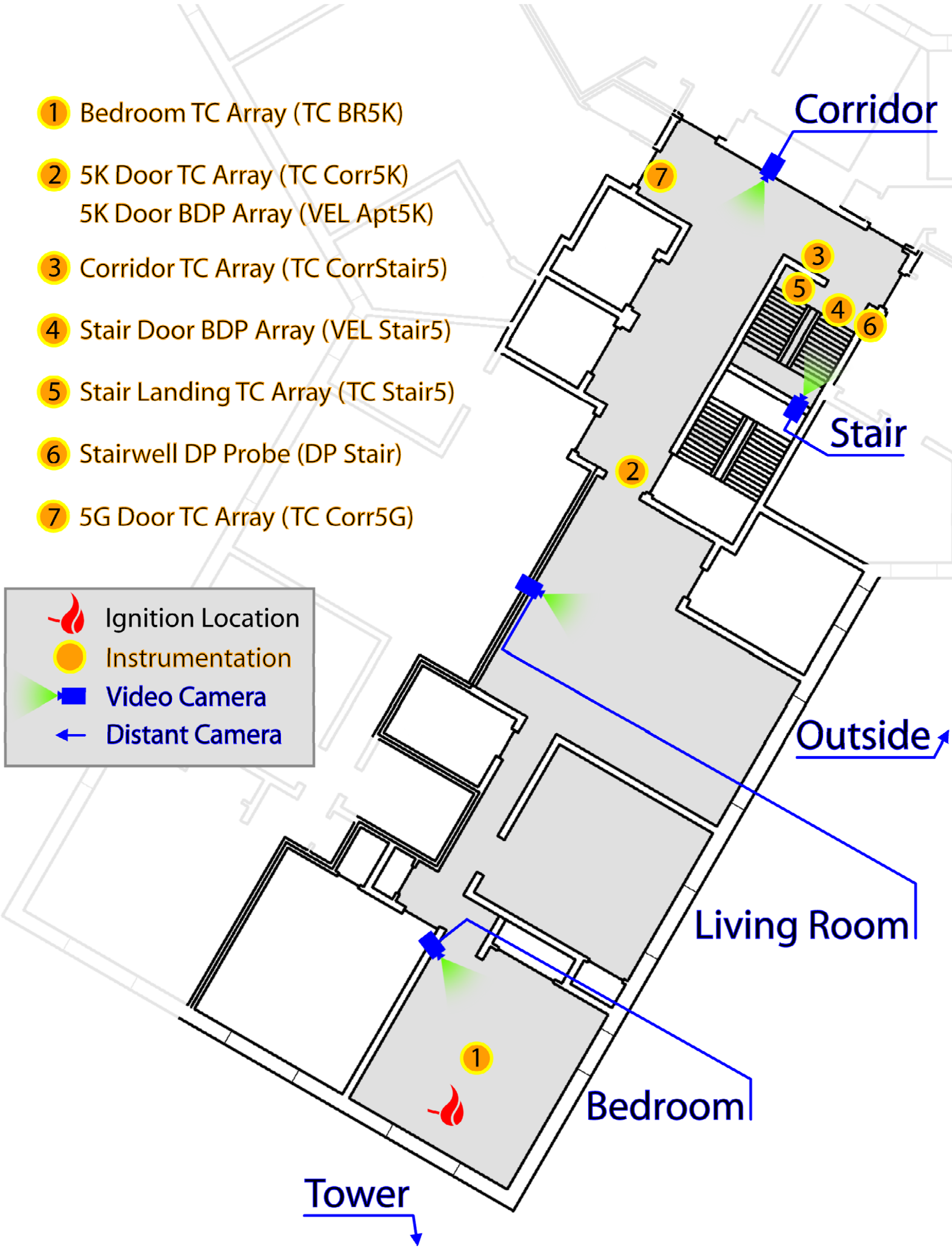



**Figure 3.8-2. Instrumentation and camera locations with labels.**

### 3.8.1 Observations

The observations are presented as a series of images captured from eight camera locations, all eight were video cameras. The camera positions inside the building are shown in Figure 3.8-2. Another outside view was added for this experiment in place of the thermal imaging view.

Figure 3.8-3 through Figure 3.8-16 present sets of eight images one from each camera position, at a given time, from the time of ignition to 32 min (1920 s) after ignition. Images were captured every 4 min and at times when events had taken place that demonstrate the experimental objectives. Each image view is labeled. The first view (BEDROOM) at the top left of each figure shows the bedroom of apartment 5K, the bedroom furthest from the apartment entrance with a view of the single window straight across, double window to the right and ignition trashcan at the foot of the bed. The top right view (LIVINGRM) was of the living room looking across to the windows. The corridor view (CORRIDOR) shows the corridor leading up to the open apartment doorway. Next to that, the outside lobby view (LOBBY) shows the area just outside the lobby doors. The view (STAIR) shows the stairwell with a camera from the floor below the fire looking up to the fire floor. Next to that is the tower view (TOWER) which shows an external view of the fire apartment. The bottom left view (ROOF) shows the bulkhead door at the top of the stairwell and the bottom right view (OUTSIDE) shows an alternate view of the outside of the apartment from a window in another wing of the building.

Figure 3.8-3 shows the images at the time of ignition. At this point, the eight video views were clear and unobstructed. The bedroom view shows the ignition trashcan near the double window and a sheet of gypsum board covering the single window. The single window was covered to prevent any loss of flow from the simulated wind.

Figure 3.8-4 shows the images at 240 s (4 min) after ignition. The fire had extended to the bed from the trash container where ignition took place. The smoke layer had descended almost to the floor in the ignition bedroom, but was approximately 1.5m (5 ft) from the floor in the living room, and was just visible at the ceiling level in the public corridor. Flames are visible from the exterior tower view but the window was still intact.

Figure 3.8-5 shows the images at 480 s (8 min) after ignition. One pane from the bedroom double window failed 176 s prior and the 5$^{th}$ floor stair A door was opened 12 s prior. The smoke layer had descended to the floor in the corridor, living room, and bedroom views; visibility in these views is near zero beyond the flames in the bedroom view. Smoke had begun to push down the stairwell. There was no visible smoke leakage from the bulkhead door at this time.

Figure 3.8-6 shows the images at 720 s (12 min) after ignition. The bulkhead door had been opened 20 s prior and smoke was venting from it. There was very little visibility in the stairwell view. The living room view shows flames beginning to enter the living room.

Figure 3.8-7 shows the images at 830 s (13 min and 50 s) after ignition. The bedroom was completely full of flames, there were flames involving the living room and moving toward the corridor. There was minimal visibility in the corridor and no visibility in the stairwell. Smoke was flowing out of the bulkhead doorway indicating that the stairwell was full of smoke to the roof.

Figure 3.8-8 shows the images at 960 s (16 min) after ignition. The bedroom double window had completely failed by this point. Flames could be seen in the stairwell view coming from the public corridor. The volume of smoke venting from the bulkhead had reduced the visibility in the roof view to zero. The WCD was being moved into place over the left half of the bedroom double window. White smoke was pushing out of the fire apartment in the area of the living room window.

Figure 3.8-9 shows the images at 975 s (16 min and 15 s) after ignition. The WCD device remained in place, blocking one half of the window. This was done to gain insight into the question, if the WCD was not big enough to block an entire window is there a benefit to blocking as much of it as possible? All other conditions in the images are similar to those from 15 s prior.

Figure 3.8-10 shows the images at 1040 s (17 min and 20 s) after ignition. The living room window has failed approximately 20 s prior and there were flames throughout the bedroom, living room, and corridor, reaching the stairwell. These were the conditions 5 s before the activation of the FBN.

Figure 3.8-11 shows the images at 1080 s (18 min) after ignition. The FBN 1 with a fog nozzle has been flowing for 35 s into the bedroom window. There was still some burning in the bedroom and there does not appear to be much impact on the amount of flames in the living room. The visibility in the stairwell and room views was still zero.

Figure 3.8-12 shows the images at 1200 s (20 min) after ignition. At this point the corridor view had been damaged and no longer provided video. The bedroom view was similarly lost by this time. FBN 1 began flowing into the bedroom double window 155 s prior and ceased 76 s prior. The bulkhead had been closed 16 s prior. Combustion in the living room was visible from that view. Flames were still extending from the failed living room window. This view was captured 20 s prior to FBN 1 flow into the living room.

Figure 3.8-13 shows the images at 1260 s (21 min) after ignition. The FBN was relocated to the living room window and flowed into the living room 41 s prior to this set of images. The water was still flowing and the visible flame in the living room was suppressed.

Figure 3.8-14, Figure 3.8-15, and Figure 3.8-16 show the images at 1440 s (24 min), 1680 s (28 min), and 1920 s (32 min) after ignition, respectively. By this time the internal views on the fire floor were limited, and the external views indicate that a majority of the fire had been suppressed. The FBN was stopped at 1295 s (21.6 min). The use of the PPV fan rekindled a fire in part of the living room and cleared the stairwell of smoke.

Figure 3.8-3. Experiment 5K, ignition.

Figure 3.8-4. Experiment 5K, 240s after ignition.

**Figure 3.8-5. Experiment 5K, 480s after ignition.**


**Figure 3.8-6. Experiment 5K, 720s after ignition.**

**Figure 3.8-7. Experiment 5K, 830s after ignition.**

Figure 3.8-8.  Experiment 5K, 960s after ignition.

**Figure 3.8-9. Experiment 5K, 975s after ignition.**

**Figure 3.8-10. Experiment 5K, 1040s after ignition.**


**Figure 3.8-11. Experiment 5K, 1080s after ignition.**


**Figure 3.8-12. Experiment 5K, 1200s after ignition.**


Figure 3.8-13.  Experiment 5K, 1260s after ignition.

**Figure 3.8-14. Experiment 5K, 1440s after ignition.**

Figure 3.8-15. Experiment 5K, 1680s after ignition.

Figure 3.8-16. Experiment 5K, 1920s after ignition.

### 3.8.2 Temperatures

Figure 3.8-17 through Figure 3.8-19 provide temperature data for five measurement locations on the fire floor at two elevations and throughout the height of the stairwell. The locations of the measurement points can be seen in Figure 3.8-2. The events that occurred during the experiment are listed on the top of the figures with lines at the time of the event. A time history for each thermocouple at each measurement location is located in Appendix D – Detailed Graphs.

Figure 3.8-17 shows the temperatures versus time at 2.1 m (7 ft) above the floor at 5 measurement locations, the bedroom, just outside the fire apartment in the corridor, just outside Apartment 5G in the corridor, just outside the A stairwell doorway, and just inside the A stairwell on the landing. The bedroom temperature increased to approximately 500 ºC (932 ºF) by 315 s prior to the bottom left window pane failing. The wind introduced into the bedroom cooled the room. Doors were opened to provide more ventilation to the fire. Ultimately the bulkhead door needed to be opened to allow the fire to grow, fail more window panes, and develop a wind driven fire. At approximately 700 s the temperature increased from 350 ºC (662 ºF) to 700 ºC (1292 ºF) and ultimately to 900 ºC (1652 ºF) after the bedroom double window completely failed. The WCD was deployed at 975 s over half of the failed window and the bedroom temperature slightly increased. At 1048 s the FBN was directed into the bedroom and the bedroom temperature decreased from approximately 900 ºC (1652 ºF) to 100 ºC (212 ºF) very quickly and remained there for the remainder of the experiment.

The corridor temperatures remained below 250 ºC (482 ºF) until 825 s when the wind driven condition was developed triggered by full bedroom involvement in flames extending into the living room. At this time the temperature in the corridor right outside the fire apartment increased from 250 ºC (482 ºF) to 650 ºC (1202 ºF) in seconds. The two other corridor temperatures increased from approximately 200 ºC (392 ºF) to above 400 ºC (752 ºF) in seconds and climbed to a steady state of approximately 600 ºC (1112 ºF) in less than 1 min. The deployment of the WCD over half of the window had no significant impact on the corridor temperatures. During the flowing of the FBN into the bedroom the corridor temperatures decreased from above 600 ºC (1112 ºF) to approximately 300 ºC (572 ºF). The temperature just outside the fire apartment recovered to above 400 ºC (752 ºF) because of the continued burning in the living room but decreased once the FBN was directed into the living room suppressing the remaining fire.

The stairwell 2.1 m (7 ft) temperature remained below 200 ºC (392 ºF) until the wind driven condition was developed. The temperature spiked quickly from 200 ºC (392 ºF) to 350 ºC (662 ºF) and steadily increased to over 600 ºC (1112 ºF). The WCD deployment had little effect on the temperature and the FBN activation decreased the stairwell temperature from 550 ºC (1022 ºF) to 250 ºC (482 ºF) while the water was flowing. The wind driven condition was eliminated once the bedroom was suppressed and the temperature decreased further once the living room was extinguished.

Figure 3.8-18 shows the temperatures at 1.2 m (4 ft) which would be more representative to where firefighters would be operating or occupants would be evacuating. The temperature at this elevation in the bedroom behaved very similarly to the 2.1 m (7 ft) temperature. This was consistent with a well mixed ventilation limited fire. This temperature was within 100 ºC (212 ºF) for most of the experiment until about 825 s when there was enough oxygen from the broken window to create flashover conditions in the bedroom. From that time on the bedroom temperatures were uniform throughout. At approximately 825 s the flow path from the bedroom to the stairwell was well mixed and the temperatures were the same as the 2.1 m (7 ft) elevation showing that there was no longer a cool layer and the temperatures were increased from floor to ceiling. After the FBN was flowed into the bedroom and living room the temperatures decreased to approximately 200 ºC (212 ºF) which would allow fire fighters to advance to the fire apartment.

Figure 3.8-19 shows the temperatures 1.2 m (4 ft) above the landing on floors 1, 2, 4, 6 and at the bulkhead. Temperatures in the stairwell above the fire floor began to escalate from 50 ºC (122 ºF), once the bulkhead door was opened and created a flow path through the bedroom and out of the top of the stairwell, to over 550 ºC (1022 ºF). The temperature on the 4th floor reached 300 ºC (572 ºF) before the deployment of the WCD. Blocking half of the flow through the bedroom window slowed the flow moving down the stairwell and decreased the temperature back down to 50 ºC (122 ºF). When the FBN was flowed into the living room and the bulkhead was closed the fire gases were pushed down the stairwell creating a temperature spike of 150 ºC (302 ºF) for a short period of time.

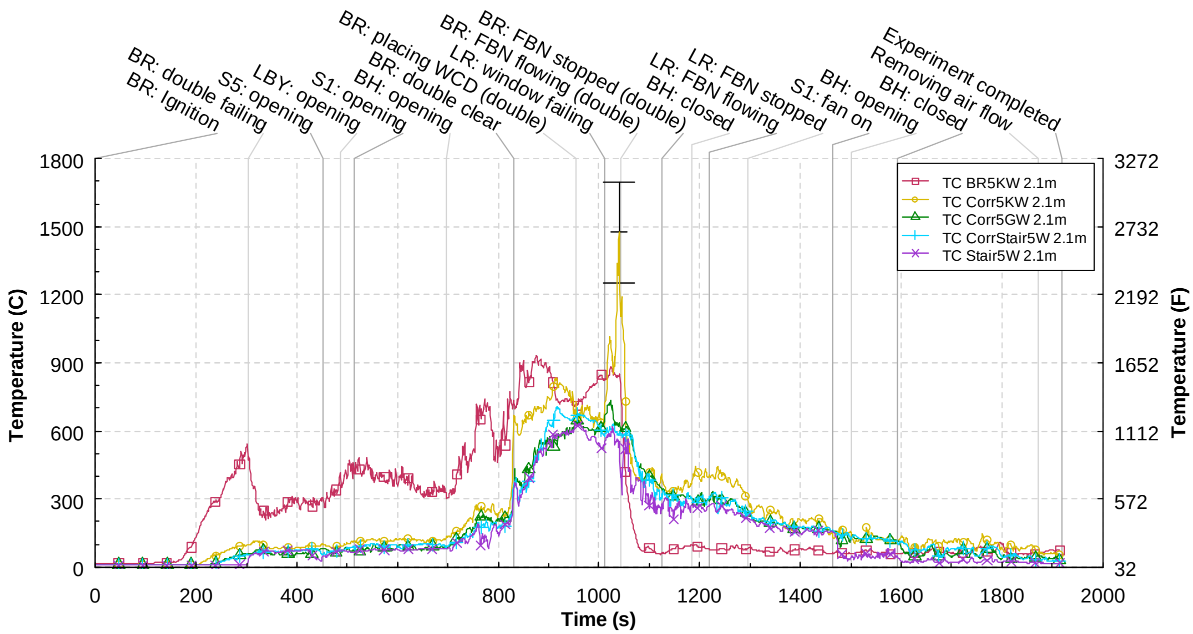



**Figure 3.8-17. 5K Temperature vs. time at 2.1 m above the floor**

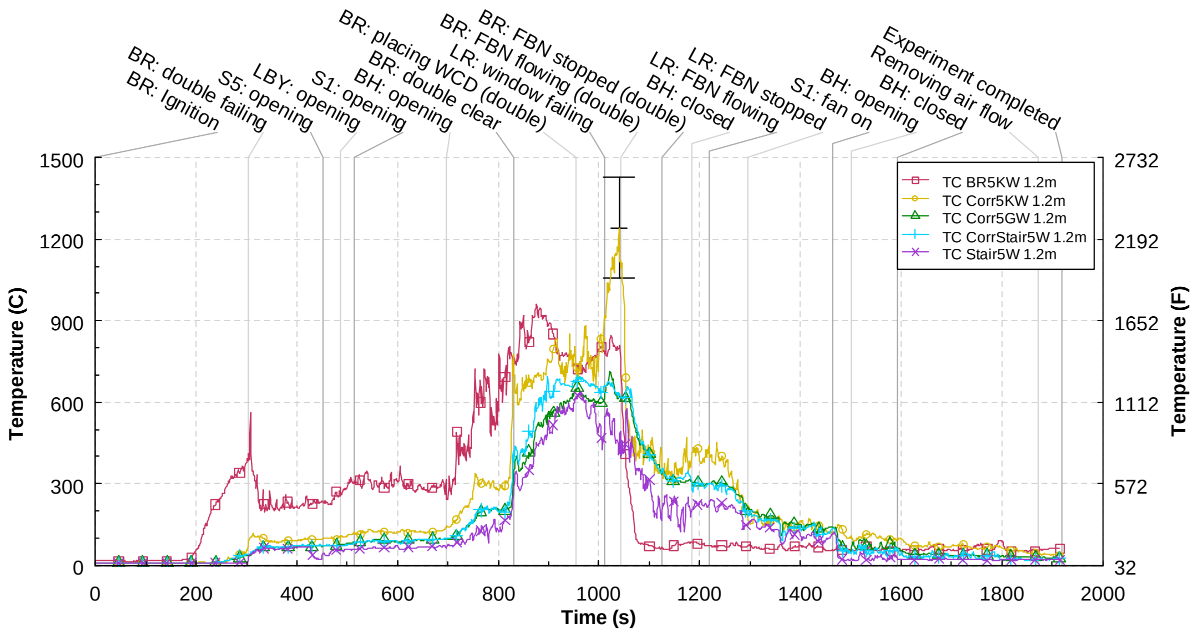



**Figure 3.8-18. 5K Temperature vs. time at 1.2 m above the floor**

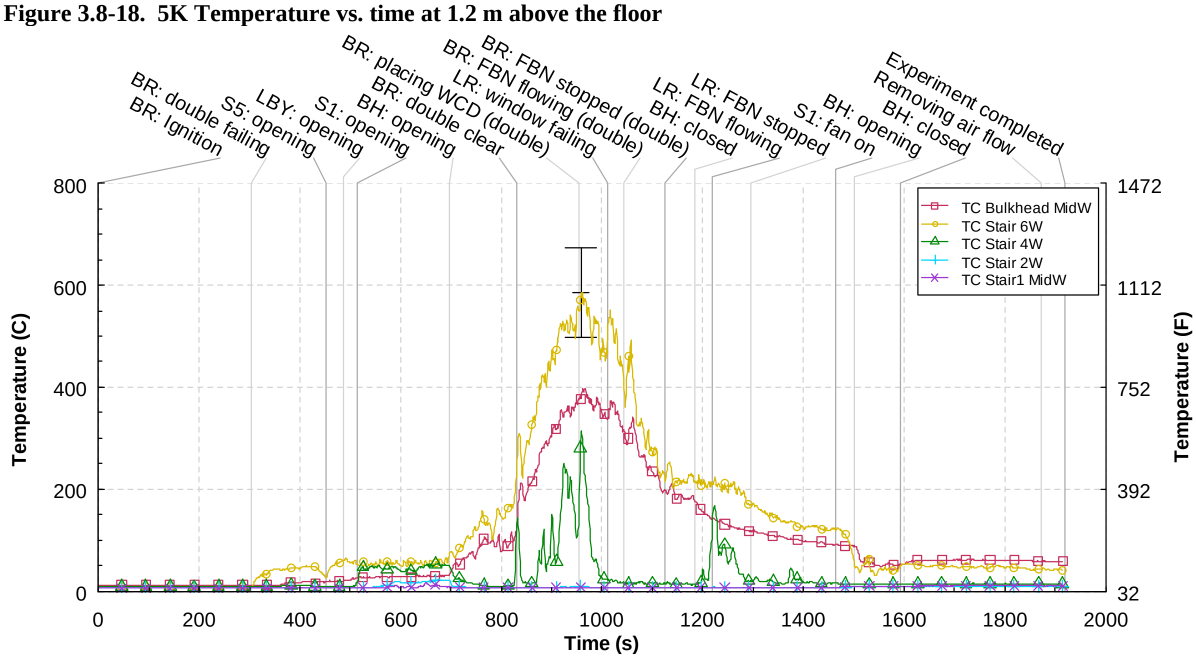



**Figure 3.8-19. 5K stairwell temperature vs. time**

## 3.8.3 Pressures

Average pressure measurements in the stairwell are shown in Figure 3.8-20. The differential pressure measurements were made at 1.2 m (4 ft) on the stairwell landing of every floor and referenced to an apartment on the same floor. With all of the doors to the stairwell closed the pressures fluctuated with an average pressure of approximately 10 Pa. The natural wind, number of damaged apartments from previous experiments and leaky stairwell doors caused the higher ambient pressures. After a window pane failed in the bedroom and the door to the stairwell was opened the pressure in the stair increased to 40 Pa at the top of the stairwell and approximately 25 Pa in the area of the fire floor. Opening the bulkhead decreased the pressure in the stairwell to below 15 Pa. The fire floor pressure remained above 25 Pa with the elevated temperatures from the wind driven fire and decreased once the WCD was deployed. The bulkhead door was closed at 1185 s and the pressure in the top three floors of the stairwell increased to above 30 Pa. Suppressing the living room fire decreased the pressures and adding the PPV fan increased the pressures in the entire stairwell to between 15 Pa and 25 Pa.

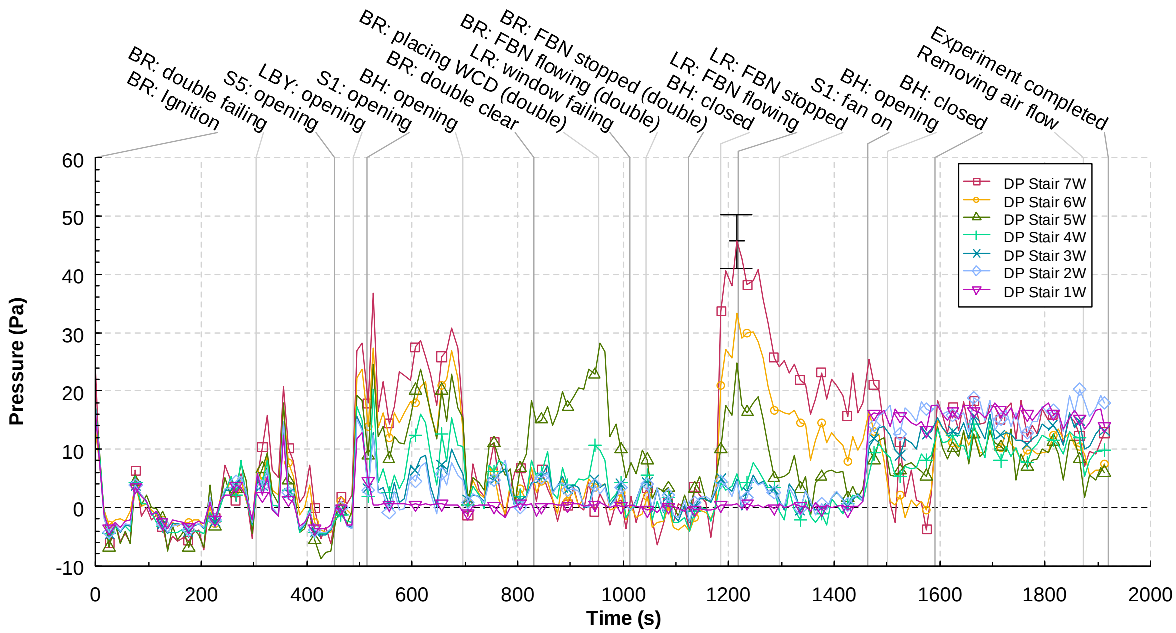



**Figure 3.8-20. 5K stairwell pressures vs. time**

### 3.8.4 Velocities

Average doorway velocities from 3 doors; the fire apartment door, the door from the fire floor to the stairwell, and the door at the base of the stairwell, were recorded versus time and shown in Figure 3.8-21. The three bi-direction probes in each door were averaged to provide the bulk flow through the doors. A time history for each probe at each measurement location is located in Appendix D – Detailed Graphs. During the wind driven condition the velocity out of the fire apartment was as high as 9 m/s (20 mph). The velocity in through the 1st floor stair door was less than 1 m/s (2 mph) for most of the experiment and increased as the PPV fan was added later in the experiment.

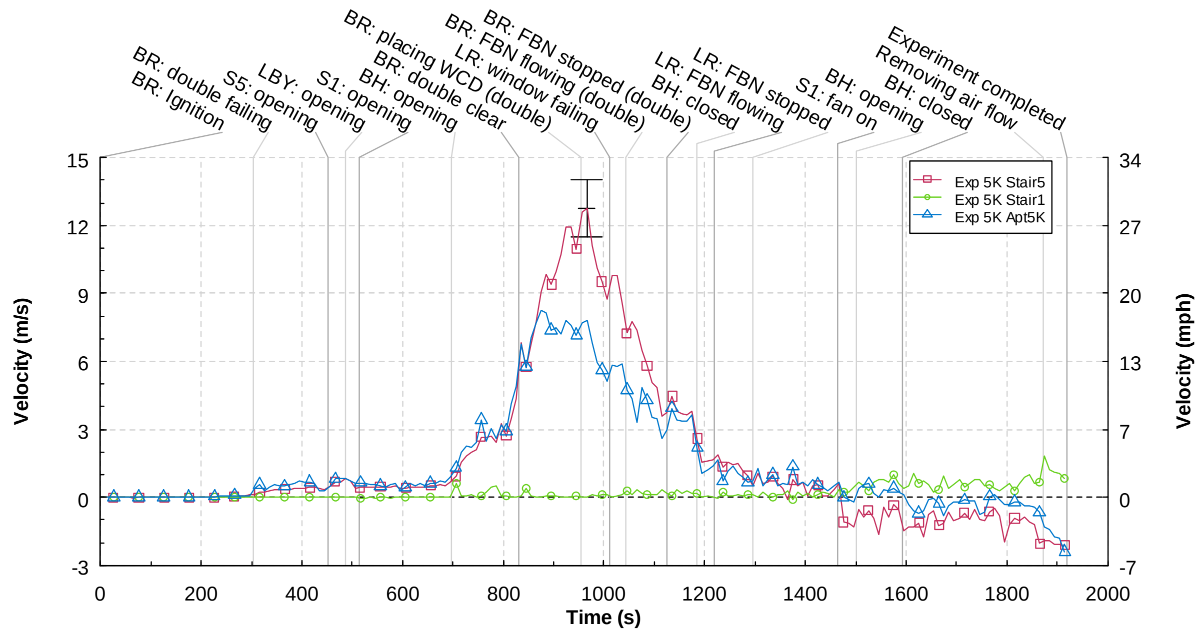



**Figure 3.8-21. 5K Velocities vs. time**

## 3.8.5 Discussion

This experiment utilized the simulated wind directed into the bedroom and a wind driven condition was created which caused extremely hazardous conditions inside the building. Temperatures exceeded 600 ºC (1112 ºF) throughout the fire floor at any elevation above the floor. These same temperatures entered the stairwell, extended to the top of the stairwell and created poor conditions from the top of the stairwell and down a floor to the 4th floor. The conditions created during this experiment were not conducive to a direct frontal fire attack and firefighters remote from the fire in the stairwell would have been threatened if they were in the flow path due to extreme temperatures.

The first pane of the bedroom window failed at 304 s and the window completely failed at 831 s. The temperature in the center of the bedroom at 1.2 m (4 ft) at the time of window failure was approximately 500 ºC (932 ºF). The temperature in the center of the room at the time of complete window failure was in excess of 900 ºC (1652 ºF). This demonstrates that when a portion of the window fails, the wind being introduced through the opening cools and slows the failure of the rest of the window. The majority of the window did not fail until the room transitioned to flashover.

Similar to previous experiments the fire took a significant amount of time to develop even with a failed window pane in the fire room. The air was forced into the bedroom but had nowhere to travel to with the exception of leaks around doors. Once the stair door was opened the fire did not grow significantly. The first floor stair door was opened but even with a downward flow the smoke layer remains down to the floor level. Once the bulkhead door was opened the flow changes to up the stairwell and the fire was able to grow quickly. The open bulkhead door contributed to the development of the wind driven condition. A flow path is required for a wind driven fire condition to occur.

The WCD device was deployed to block one half of the bedroom window. This was to gain insight into the question, if the WCD was not big enough to block an entire window, or if it can not be positioned into place, is there a benefit to blocking as much of it as possible and if you block half of the flow do you create better conditions in the structure? With the WCD in place, the conditions on the fire floor did not improve much. The greatest impact was in the stairwell. With half of the window blocked the temperatures below the fire floor returned to near ambient. This indicates that with the entire double window unblocked there was enough flow to split and move both up and down the stairwell. However with half the inlet area the flow did not have enough energy to split and the flow path up the stairwell could support the total flow.

The 10.1 L/s (160 gpm) flow from the FBN 1 with a fog nozzle, directed into the bedroom, suppressed the bedroom fire. When the nozzle was flowing, the temperatures throughout the fire floor decreased. During the flowing of the FBN the corridor temperatures decreased from above 600 ºC (1112 ºF) to approximately 300 ºC (572 ºF). These temperatures were still above those that support fire fighters advancing down the corridor but the burning gases were stopped. Stairwell temperatures dropped to below 200 ºC (392 ºF) which would allow control to be gained of that door if it was lost previously. The flow into the bedroom did not suppress the living room fire which had vented itself out of the living room windows. The nozzle was redeployed to the living room window on the floor below and the fire was suppressed. This created conditions that would allow firefighters to advance and complete extinguishment and other operations on the fire floor.

The use of the PPV fan after fire suppression reduced temperatures in the stairwell and returned visibility faster than if natural ventilation was used. Even with the fire suppressed, there was still smoke and hot gases being produced and the fan allowed these combustion products to be limited to the floor of origin and not spread throughout the stairwell.

## 3.9 Experiment 5A

The ninth experiment was located on the 5th floor in apartment 5A. Experiment 5A was ignited in the bedroom furthest from the open apartment door (Figure 3.8-1). This experiment also utilized a simulated wind provided by the MVU. The simulated wind was subjected to the bedroom double window at a magnitude of approximately 9 m/s to 11 m/s (20 mph to 25 mph). The events that took place during the experiment to accomplish the experimental objectives bulleted below are shown in Table 3.9-1.

Experimental Objectives

- Create wind driven fire conditions from a bedroom fire
- Examine window failure times and conditions
- Examine building flows with different door opening configurations
- Examine impact of the deployment of a WCD on fire room window
- Control wind driven conditions with FBN in conjunction with WCD
- Utilize portable PPV fans to control smoke movement

The results for the experiment are presented in the following sections: observations, temperature, pressure, velocity, and discussion. Figure 3.8-2 shows the camera names and locations used in the observation section and the instrumentation names and locations used in the temperature, pressure and velocity sections.

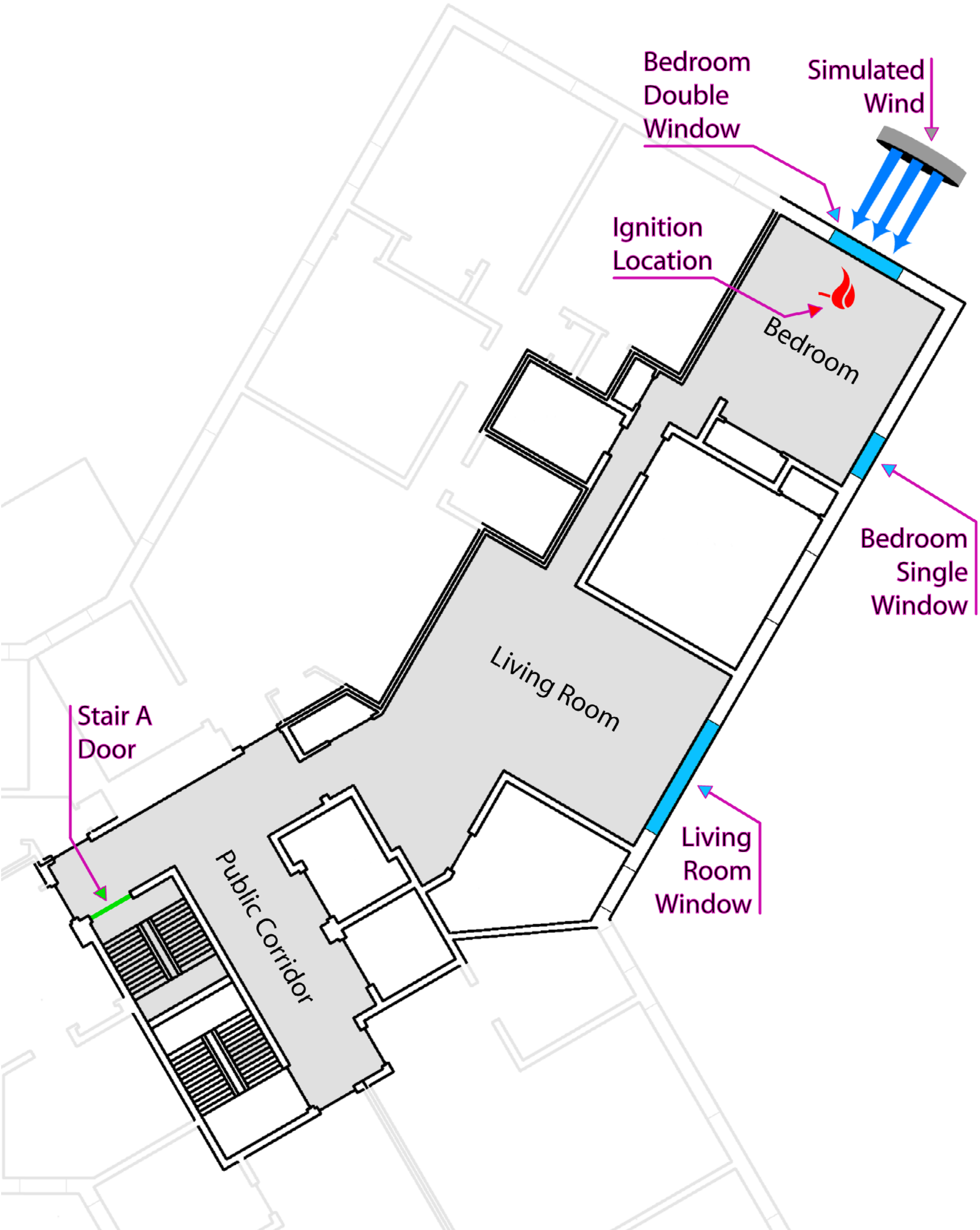



**Figure 3.9-1. 5th floor apartment A floor plan with locations pertinent to Experiment 5A**

**Table 3.9-1: Experiment 5A Timeline**

| Start (s) | End (s) | Event Location | Event Description |
|---|---|---|---|
| 0 | 0 | Bedroom | Ignition |
| 234 | 234 | Bedroom double | Bottom right pane failed |
| 322 | 325 | Front lobby | Right door opened |
| 359 | 361 | 1st floor stair A | Door opened |
| 430 | 436 | 5th floor stair A | Door opened |
| 528 | 532 | Bulkhead door | Opened |
| 588 | 588 | Bedroom double | Top right pane failed |
| 605 | 606 | Bedroom single | Top pane failing |
| 635 | 635 | Bedroom double | Bottom left pane failed |
| 660 | 661 | Bedroom double | Top left pane failed |
| 820 | 825 | Bulkhead door | Closed |
| 831 | 832 | Bedroom single | Bottom pane failed |
| 847 | 847 | Bedroom single | Clear |
| 895 | 902 | Bedroom double | WCD deployed |
| 986 | 996 | Front lobby | 2 - 27 inch fans activated |
| 1304 | 1336 | Bedroom double | WCD bottom corner peeled back |
| 1373 | 1373 | Bedroom double | FBN 2 started flowing (fog), blocked by WCD |
| 1378 | 1382 | Bedroom double | WCD bottom corner peeled away from nozzle |
| 1404 | 1404 | Bedroom double | FBN 2 stopped |
| 1573 | 1573 | Experiment completed | |

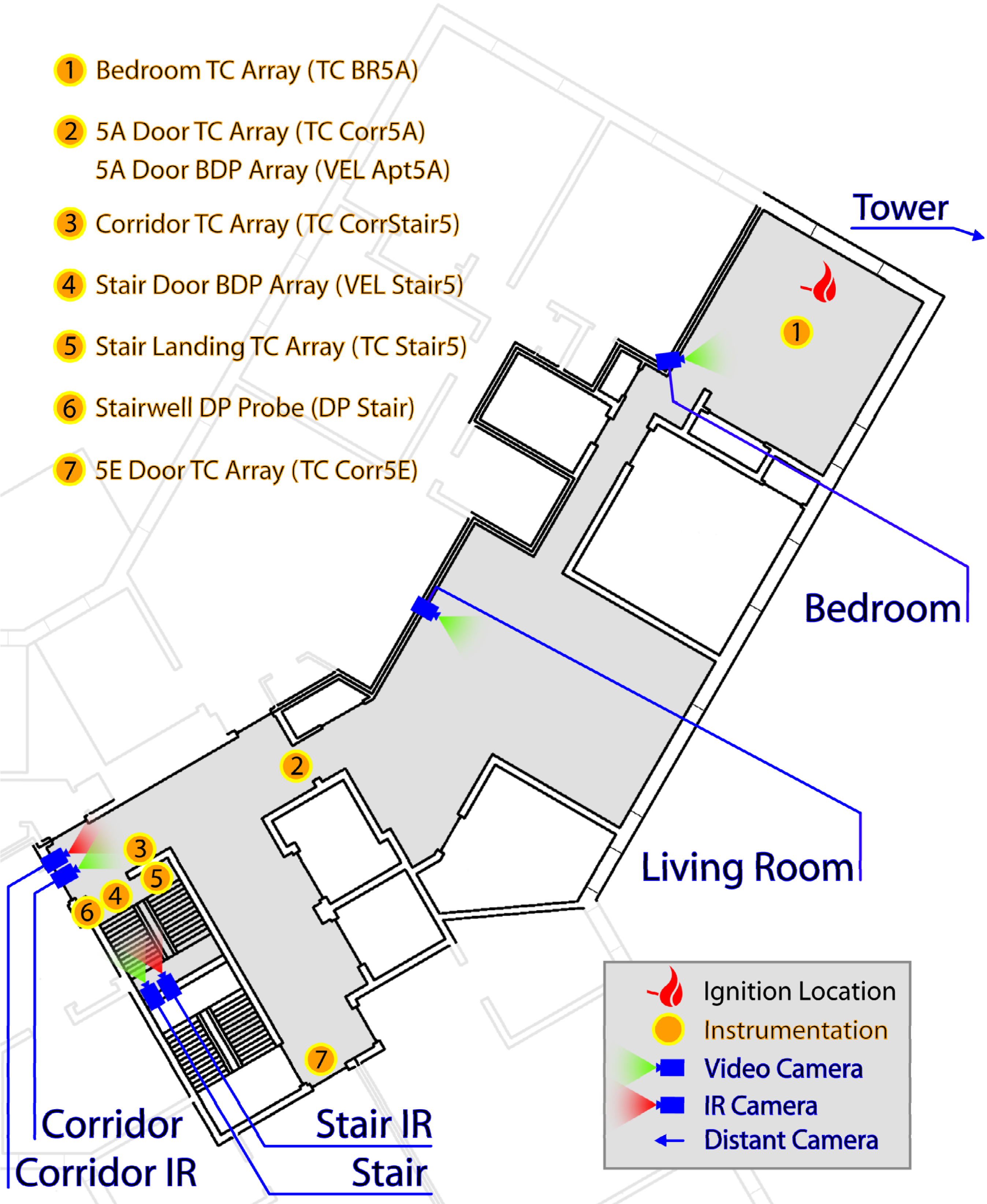



**Figure 3.9-2. Instrumentation and camera locations with labels.**

### 3.9.1 Observations

The observations are presented as a series of images captured from eight camera locations, seven were video cameras and one was a thermal imaging cameras. The camera positions inside the building are shown in Figure 3.9-2.

Figure 3.9-3 through Figure 3.9-16 present sets of eight images one from each camera position, at a given time, from the time of ignition to 24 min (1440 s) after ignition. Images were captured every 4 min and at times when events had taken place that demonstrate the experimental objectives. Each image view is labeled. The first view (BEDROOM) at the top left of each figure shows the bedroom of apartment 5A, the bedroom furthest from the apartment entrance with a view of the single window straight across, double window to the right and ignition trashcan at the foot of the bed. The top right view (LIVINGRM) was of the living room looking across to the windows. The corridor view (CORRIDOR) shows the corridor leading up to the open apartment doorway. Next to that, the outside lobby view (LOBBY) shows the area just outside the lobby doors. The next two views (STAIR and STAIR IR) show the stairwell with a visual and a thermal imaging camera from the floor below the fire looking up to the fire floor. The bottom left view (ROOF) shows the bulkhead door at the top of the stairwell and the bottom right view (OUTSIDE) shows an external view of the fire apartment.

Figure 3.9-3 shows the images at the time of ignition. At this point, the seven video views were clear and unobstructed. However, the thermal image provided limited thermal contrast because the surfaces in the view are at nearly equal temperature. Soot and thermal damage visible in the corridor and stair views are from previous experiments

Figure 3.9-4 shows the images at 240 s (4 min) after ignition. The bedroom double window began to fail 6 seconds prior. Smoke had reached the floor in the living room, corridor, and bedroom views; a significant volume of smoke was leaking around the closed 5$^{th}$ floor stair A door as well.

Figure 3.9-5 shows the images at 420 s (7 min) after ignition. At this point the front lobby door is open and the 1$^{st}$ Floor door to stair A has been open for a minute. The smoke level in stair A is moving below the 5$^{th}$ floor landing and the thermal imager view shows that the area around the stair door has become hotter.

Figure 3.9-6 shows the images at 440 s (7 min and 20 s) after ignition. These images were recorded 4 s after the 5$^{th}$ stair door was opened. The fire continued to burn in the bedroom. Smoke obscuration in the stair increased after the door to the fire floor was opened.

Figure 3.9-7 shows the images at 480 s (8 min) after ignition. No changes had been made since the 5$^{th}$ stair door was opened. Conditions in the stair continued to decay. Visibility was nearly zero in the stairwell view, and the stair IR view was saturated by hot gases.

Figure 3.9-8 shows the images at 600 s (10 min) after ignition. These images were recorded approximately 1 min after the bulkhead door was opened and 12 seconds after the top right pane of the bedroom double window failed. The increased ventilation to the fire apartment enabled the flames to spread to the living room. The visibility in the corridor and the stair had improved by a small amount.

Figure 3.9-9 shows the images at 720 s (12 min) after ignition.  At this point the bedroom double window had completely failed and the top portion of the bedroom single window had cracked and was leaking smoke.  The fire had intensified in the bedroom.  Flames were no longer visible in the living room.  Smoke was venting from the open bulkhead door.

Figure 3.9-10 shows the images at 890 s (14 min and 50 s) after ignition.  At 847 s the bedroom single window failed (opened) completely.  As a result of both the window and door openings to the bedroom the excess fuel in the hot gas layer burned away and the fire was reduced to flames attached to the burning objects in the room.  The bulkhead door was closed approximately 1 min before the images were recorded.  The conditions in the stair had not changed significantly

Figure 3.9-11 shows the images at 910 s (15 min and 10 s) after ignition.  The WCD deployment, over the bedroom double window opening, was completed 8 s before the images were recorded.  Flames were extending out of the bedroom single window opening.

Figure 3.9-12 shows the images at 960 s (16 min) after ignition.  The flames which had been pushing out of the bedroom single window had withdrawn by this point.  The hot gas layer in the living room had increased in thickness.

Figure 3.9-13 shows the images at 1200 s (20 min) after ignition.  The two 27 inch  fans positioned in front of the lobby doors were activated 204 s prior.  The fuel throughout the bedroom had largely burned out.  The fans had improved visibility from the stair through the corridor and into the fire apartment, by venting the smoke through the bedroom single window opening.

Figure 3.9-14 shows the images at 1365 s (22 min and 45 s) after ignition; approximately 30 s after the WCD was partially removed.  The reintroduction of wind into the bedroom increased the fire size and flames were observed exiting the bedroom single window opening.

Figure 3.9-15 shows the images at 1385 s (23 min and 5 s) after ignition.  FBN 2 had been deployed and was flowing 160 gpm.  The fire in the bedroom was suppressed and steam was being forced out of the bedroom window openings.  Visibility in the stair improved.

Figure 3.9-16 shows the images at 1440 s (24 min) after ignition.  The water had flowed into the bedroom unobstructed for approximately 20 s.  Some debris in the bedroom was still burning.  Smoke had not yet cleared.

Figure 3.9-3. Experiment 5A, ignition.


**Figure 3.9-4. Experiment 5A, 240s after ignition.**

Figure 3.9-5. Experiment 5A, 420s after ignition.


**Figure 3.9-6. Experiment 5A, 440s after ignition.**

Figure 3.9-7. Experiment 5A, 480s after ignition.

Figure 3.9-8. Experiment 5A, 600s after ignition.

Figure 3.9-9. Experiment 5A, 720s after ignition.


**Figure 3.9-10. Experiment 5A, 890s after ignition.**

**Figure 3.9-11. Experiment 5A, 910s after ignition.**

Figure 3.9-12. Experiment 5A, 960s after ignition.


**Figure 3.9-13. Experiment 5A, 1200s after ignition.**


**Figure 3.9-14. Experiment 5A, 1365s after ignition.**

Figure 3.9-15.  Experiment 5A, 1385s after ignition.


Figure 3.9-16. Experiment 5A, 1440s after ignition.

### 3.9.2 Temperatures

Figure 3.9-17 through Figure 3.9-19 provide temperature data for five measurement locations on the fire floor at two elevations and throughout the height of the stairwell. The locations of the measurement points can be seen in Figure 3.9-2. The events that occurred during the experiment are listed on the top of the figures with lines at the time of the event. A time history for each thermocouple at each measurement location is located in Appendix D – Detailed Graphs.

Figure 3.9-17 shows the temperatures versus time at 2.1 m (7 ft) above the floor at 5 measurement locations, the bedroom, just outside the fire apartment in the corridor, just outside Apartment 5E in the corridor, just outside the A stairwell doorway, and just inside the A stairwell on the landing. Opening the bulkhead door at 532 s, coupled with the partially opened bedroom double window resulted in the bedroom transitioning through flashover. As the bedroom double window vented completely, temperatures throughout the 5th floor increased. Note that the temperatures in the flow path were higher, while the temperature measurement position in front of Apartment 5E, out of the flow path, provided the lowest temperature. The deployment of the WCD at approximately 900 s reduced the temperature in the bedroom by almost 200 ºC (392 ºF). The addition of the two PPV fans in front of the lobby door provided additional temperature reductions in the stair and throughout the 5th floor. Partial removal of the WCD at approximately 1330 s resulted in increased temperatures in the bedroom and downstream locations, until the fire was suppressed with the FBN.

Figure 3.9-18 shows the temperatures at 1.2 m (4 ft) which would be more representative to where firefighters would be operating or occupants would be evacuating. The temperature time histories at 1.2 m (4 ft) above the floor in this experiment are very similar to the temperature time histories at 2.1 m (7 ft) above the floor.

Figure 3.9-19 shows the temperatures 1.2 m (4 ft) above the landings on floors 1, 2, 4 and at the landing above the 7th floor with access to the roof. The temperatures at the bulkhead level began to increase first as the hot gases that leaked past the 5th floor stair door rose to the top of the stairwell. After the 5th floor stair door was opened, the temperatures at the bulkhead decreased, while the temperatures at the remaining measurement positions in the stairwell increased. Opening the bulkhead door reduced the temperatures throughout the stairwell, until the bedroom transitioned to flashover. Then the temperatures at the 4th floor landing and the bulkhead landing increased. After the bedroom single window failed, the temperature at the bulkhead landing decreased, but the temperatures increased at the 4th and 2nd floor landings. Once the WCD was deployed, the temperatures throughout the stairwell were reduced. The addition of the PPV fans brought all the temperatures to near ambient conditions, with the exception of the bulkhead landing. The temperatures at the bulkhead landing were down to approximately 100 ºC (212 ºF), until the WCD was partially removed. Then the temperatures at the 4th floor landing and the bulkhead increased until the end of the experiment. The temperature at the 4th floor decreased to ambient temperatures during the period of water application.

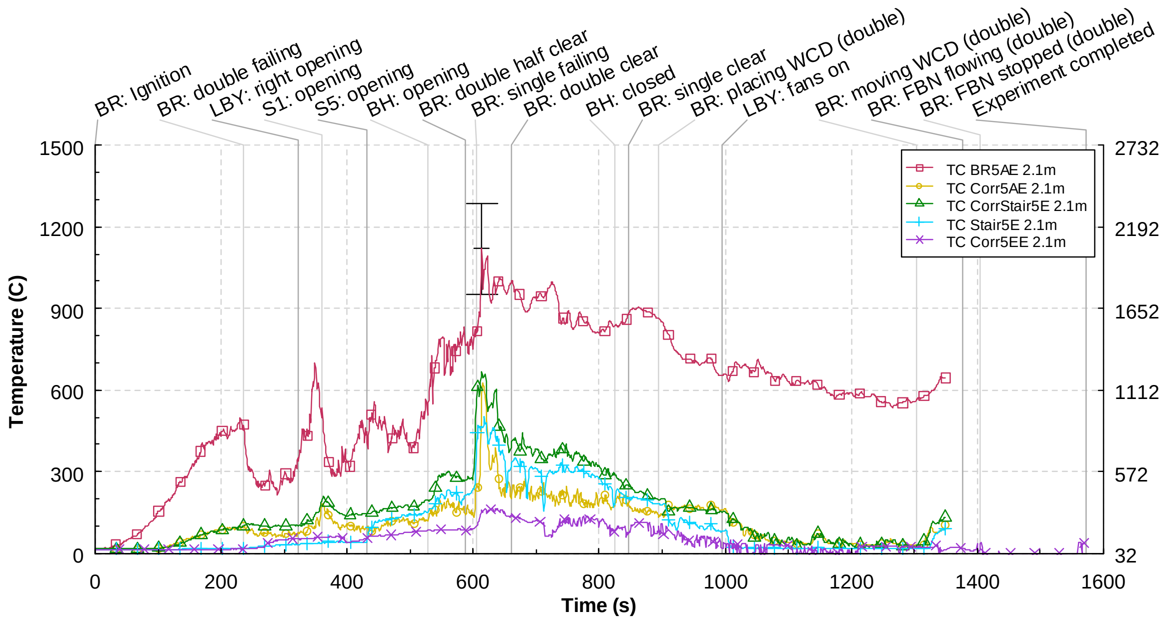



**Figure 3.9-17. 5A Temperature vs. time at 2.1 m above the floor**

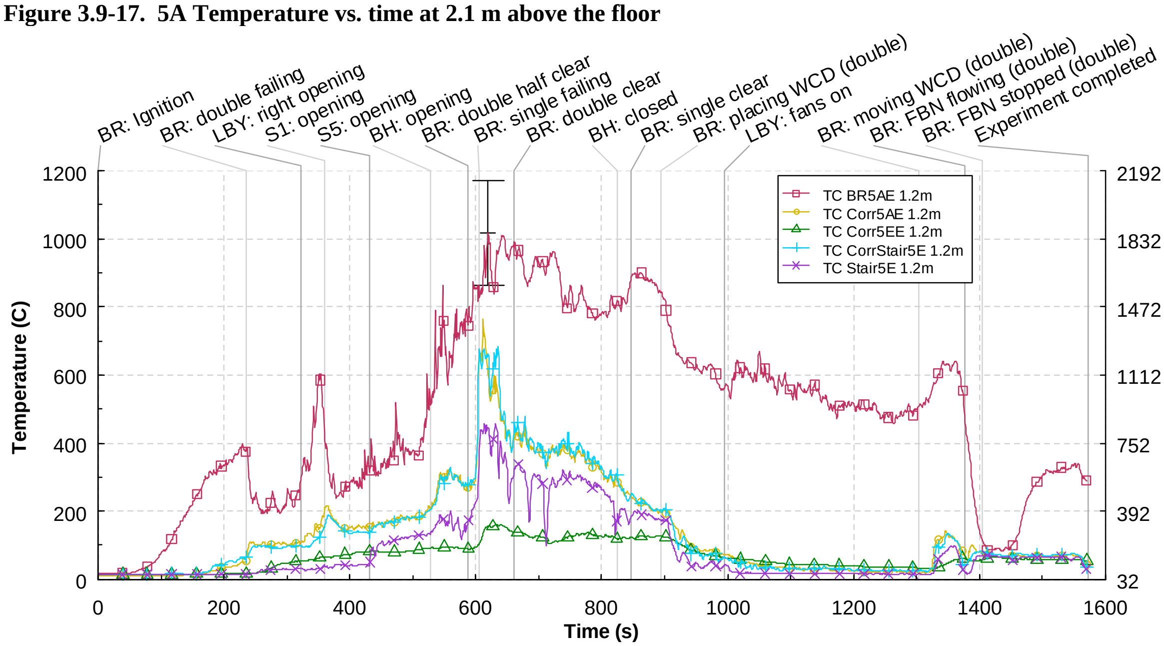



**Figure 3.9-18. 5A Temperature vs. time at 1.2 m above the floor**

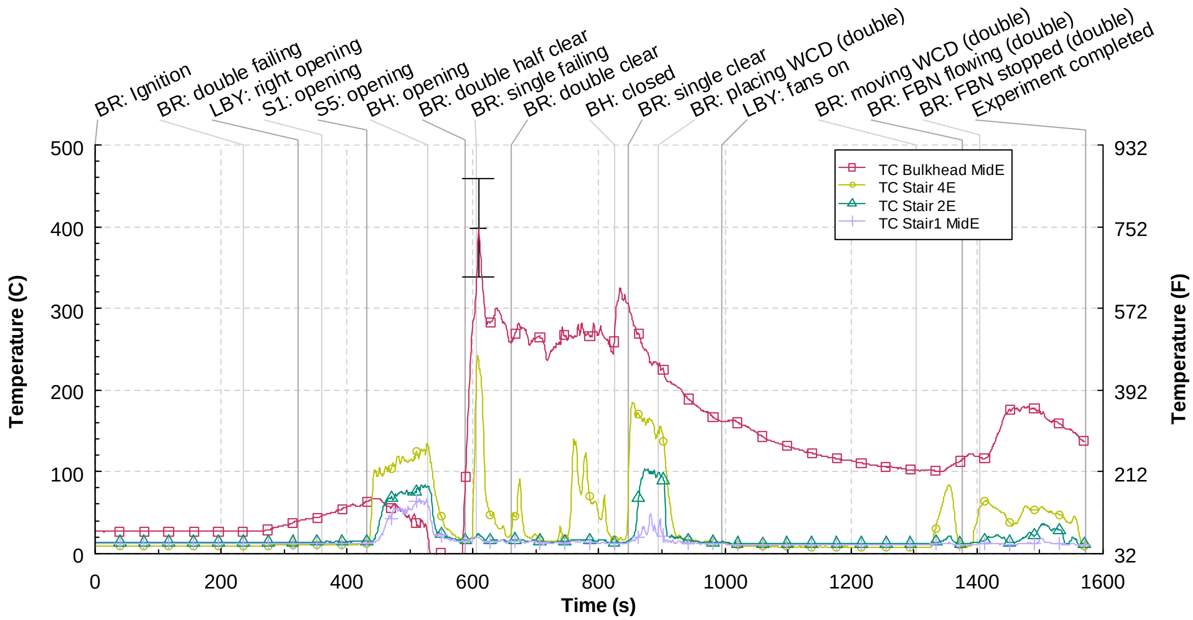



**Figure 3.9-19. 5A stairwell temperature vs. time**

### 3.9.3 Pressures

Average pressure measurements in the stairwell are shown in Figure 3.9-20. The differential pressure measurements were made at 1.2 m (4 ft) on the stairwell landing of every floor and referenced to an apartment on the same floor. With all of the doors to the stairwell closed the pressures remained below 5 Pa and only fluctuated slightly. After the 5th floor stair door was opened the pressure in the stair increased with the pressures above the fire floor above 30 Pa.

The impact of opening the bulkhead door was a drop in pressure throughout the height of the stairwell. The pressures increased again for the period between 588 s (venting of the top right portion of the bedroom double window and 606 s (venting of the top portion of the bedroom single window). Pressures in the stair remained low until the bulkhead door was closed at 825 s.

Pressures in the stairwell ranged from near 0 Pa at the 1st floor up to approximately 60 Pa at the floors above the fire floor. Deploying the WCD reduced all of the pressures in the stairwell to less than 10 Pa. The PPV fans increased the pressures in the stair to a range of 10 to 20 Pa. Once the WCD was partially removed, the pressure from the wind drove the pressures in the stairwell up to approximately 40 Pa. The period of suppression, led to another decrease in pressure in the stairwell.

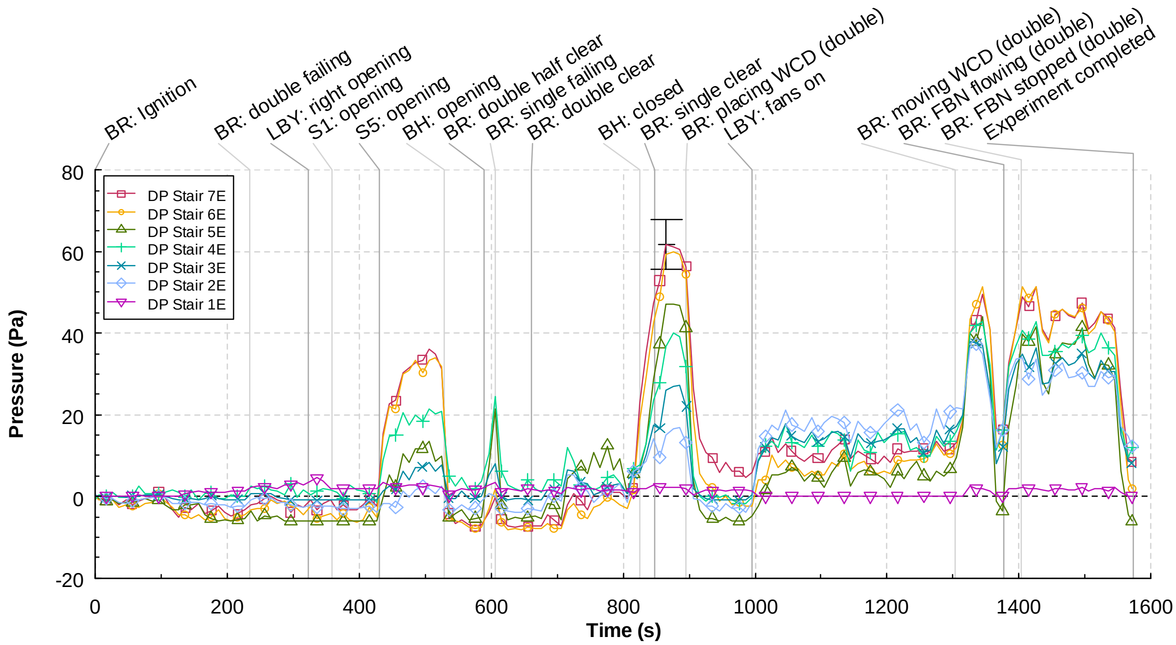



**Figure 3.9-20. 5A stairwell pressures vs. time**

### 3.9.4 Velocities

Average doorway velocities from 3 doors; the fire apartment door, the door from the fire floor to the stairwell, and the door at the base of the stair, were recorded versus time and shown in Figure 3.9-21. The three bi-directional probes in each door were averaged to provide the bulk flow through the doors. The peak velocities on the fire floor occurred with the bulkhead door open and half of the bedroom double window open. With the WCD in place, the PPV fans were able to reverse the flow through the fire floor. A time history for each probe at each measurement location is located in Appendix D – Detailed Graphs.

The velocity reinforces the concept of the flow path. Prior to the failure of the upwind window in the bedroom, (room of fire origin), there is no significant flow out of the apartment 5A. After panes of the upwind window began to self vent, the flow out of the apartment began to increase. Providing a potential flow path between the fire apartment and the 1st floor, by opening the lobby doors, the 1st floor stair door and the 5th floor stair door, increased the flow from the fire apartment to approximately 2 m/s (4 mph). Given that the combustion products entering the stairwell are buoyant, they have tendency to flow up instead of down the stairs. Hence when the bulkhead door was opened to provide an flow path to the roof, the velocity into the stair increased to approximately 4 m/s (9 mph). With this “preferred” flow path from the upwind window to the bulkhead open the fire continued to grow, additional portions of the window failed and the velocity out of the apartment and into the stair peaked at approximately 6 m/s (13 mph). The impact of closing the bulkhead door at 825 s after ignition reduced the flow out of the fire apartment to less than 1 m/s (2 mph). With the WCD was in place and the bulkhead door closed, the wind driven conditions were stopped. By using PPV fans on the 1st floor, the flow into the stairwell was reversed as fresh air was pushed from the higher pressure in the stairwell onto the fire floor and back through the fire apartment. This flow continued until the WCD was removed and suppression began.

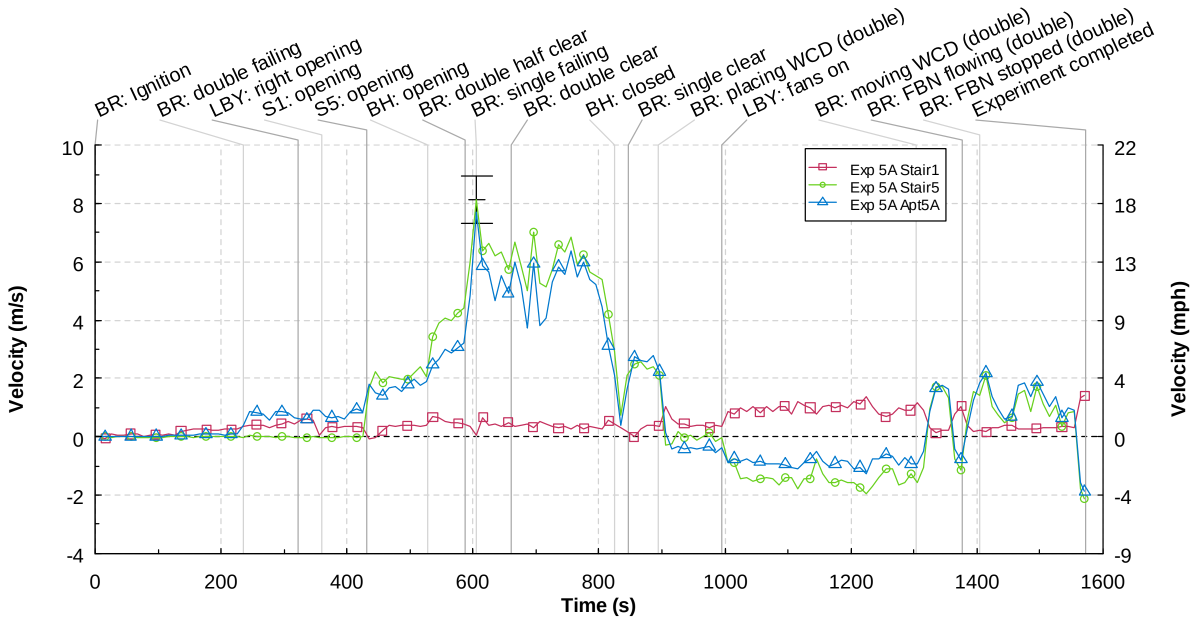



**Figure 3.9-21. 5A Velocities vs. time**

### 3.9.5 Discussion

In this experiment, a simulated wind driven fire condition was created which caused extremely hazardous conditions inside the building. The peak temperatures were generated by the creation of a flow path between the bedroom and the vented stairwell. The failure (self venting) of half of the bedroom double window combined with the open door between the fire floor and the stairwell and the open bulkhead door at the top of the stair led to the creation of a flow path. Temperatures in the flow path between the open bedroom window and the 5$^{th}$ floor stair exceeded 400 ºC (752 ºF) throughout the fire floor at both the 2.1 m (7 ft) and 1.2 m (4 ft) elevations above floor level. Heat and smoke entered the stair, resulting in poor visibility and increased temperatures both above and below the fire floor. In addition, the ventilation condition caused by the venting and doors resulted in a peak gas velocity of approximately 8 m/s (18 mph) on the fire floor. The thermal conditions created during this experiment were not conducive to a direct frontal fire attack and firefighters remote from the fire in the stairwell would have been threatened if they were in the flow path due to extreme temperatures.

The first pane of the bedroom window failed at 234 s and the window completely failed at 661 s. The temperature in the center of the bedroom at 1.2 m (4 ft) at the time of window failure was approximately 400 ºC (752 ºF). The temperature in the center of the room at the time of complete window failure was in excess of 900 ºC (1652 ºF). This demonstrates that when a portion of the window fails the wind being introduced through the opening cools and slows the development of the fire and the failure of the remaining sections of this type of window. However, given the fuel load, the partial failure of the window and the ventilation from the open stair door on the fire floor provided the oxygen required to achieve flashover. The majority of the window did not fail until after the room transitioned to flashover.

Similar to previous experiments, the fire took a significant amount of time to develop even with a failed window pane in the fire room. The air was forced into the bedroom but had nowhere to travel to with the exception of leaks around doors. Once the stair door was opened the fire began to grow slowly.

With the first floor stair door opened heat and smoke were pushed down the stairs. This flow was reversed at approximately 530 s when the bulkhead door was opened. Once the bulkhead door was opened, the pressure in the stairwell dropped and the hot gases flowed up the stairwell. This increase in flow through the fire apartment enabled the fire grow rapidly. The open bulkhead door provided the flow path needed to draw fire out of the room of origin and enable the thermal hazards of a wind driven condition on the fire floor. In this experiment the most notable changes in temperature, pressure and velocity were caused by opening or closing the bulkhead door. This shows that interrupting the flow path, anywhere on the flow path, can have a significant effect on the thermal conditions in the structure.

The WCD device was only deployed over the upwind bedroom double window only. This was done to examine the effect that another open vent to the outside (bedroom single window) would have on the conditions in the building and what impact, if any, it would have on the WCD. The deployment was completed at approximately 900 s; more than a minute after the bulkhead door was closed. With the WCD in place the temperatures in the bedroom decreased from approximately 800 ºC (1472 ºF) to 600 ºC (1112 ºF). Temperatures at other locations on the fire floor and the stairwell also decreased.

The introduction of PPV, approximately 90 s after the deployment of the WCD, pressurized the stairwell and as a result reversed the flow of combustion products back through the fire apartment to be vented out of the bedroom single window opening. The PPV fans improved the visibility and reduced the temperatures in the stairwell.

The 10.1 L/s (160 gpm) flow from the FBN 2 with a fog nozzle, directed into the bedroom, rapidly suppressed the decaying bedroom fire. The FBN only flowed water for approximately 30 s. While the water was flowing, the temperature in the bedroom decreased from approximately 600 ºC (1112 ºF) to approximately 100 ºC (212 ºF). Since the WCD was partially removed, after the water flow was stopped, the temperatures increased due to the wind pushing heat from the bedroom through the fire floor and into the stairwell.

## 3.10 Experiment 5G

The tenth experiment was located on the 5th floor in apartment 5G. Experiment 5G was ignited in the bedroom furthest from the open apartment door (Figure 3.10-1). This experiment also utilized a simulated wind provided by the MVU. The simulated wind was subjected to the bedroom double window at a magnitude of approximately 9 m/s to 11 m/s (20 mph to 25 mph). The events that took place during the experiment to accomplish the experimental objectives bulleted below are shown in Table 3.10-1.

Experimental Objectives

- Create wind driven fire conditions from a bedroom fire
- Examine window failure times and conditions
- Examine building flows with different door opening configurations
- Examine impact of the deployment of a WCD on fire room window
- Utilize portable PPV fans to control smoke movement

The results for the experiment are presented in the following sections: observations, temperature, pressure, velocity, and discussion. Figure 3.10-2 shows the camera names and locations used in the observation section and the instrumentation names and locations used in the temperature, pressure and velocity sections.

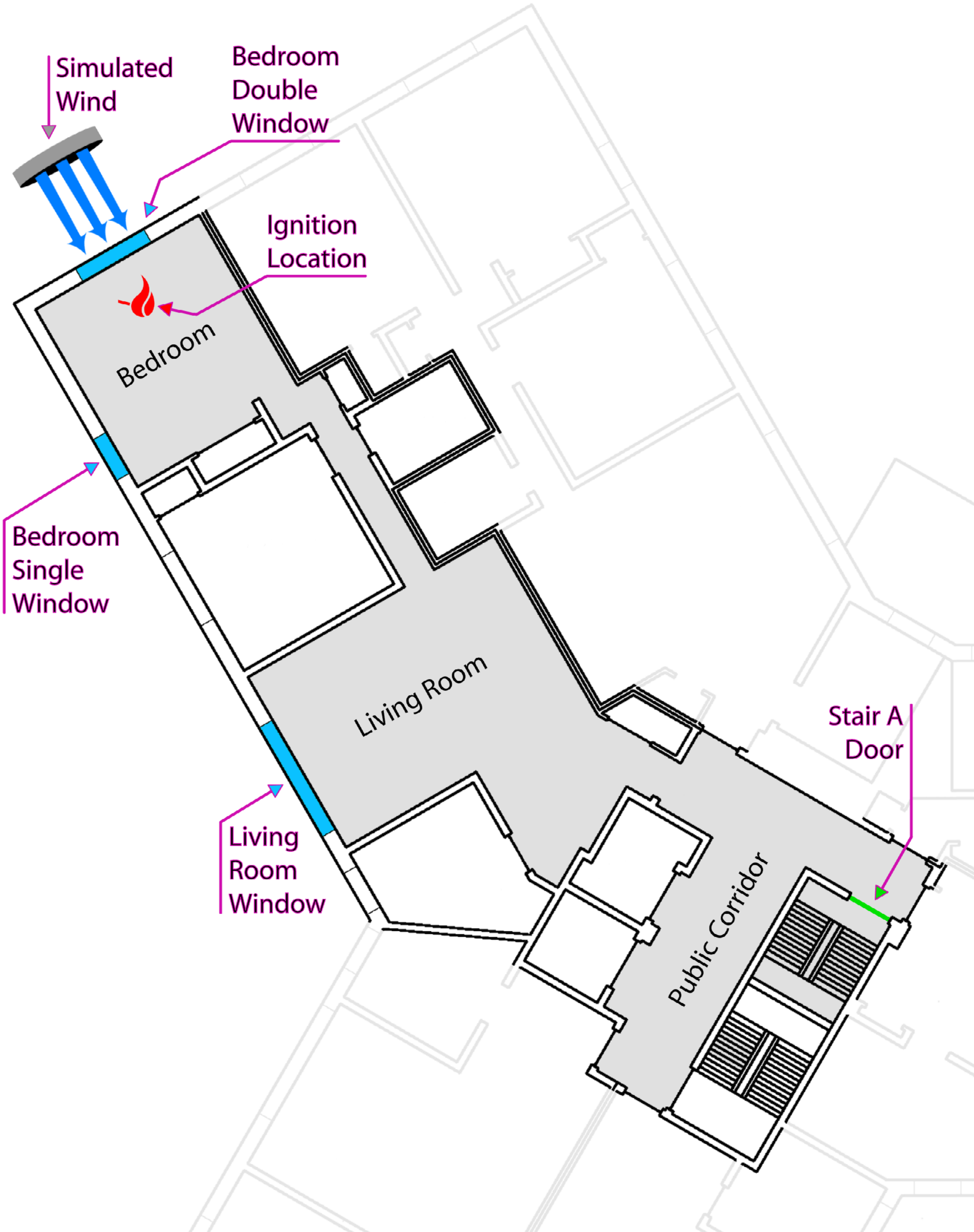



**Figure 3.10-1. 5th floor apartment G floor plan with locations pertinent to Experiment 5G**

**Table 3.10-1: Experiment 5G Timeline**

| Start (s) | End (s) | Event Location | Event Description |
|---:|---:|---|---|
| 0 | 0 | Bedroom | Ignition |
| 425 | 425 | Bedroom double | Bottom left pane failed |
| 491 | 493 | Front lobby | Left door opened |
| 503 | 506 | 1st floor stair A | Door opened |
| 541 | 549 | 5th floor stair A | Door opened |
| 569 | 576 | Bulkhead door | Opened 0.02 m (0.75 in) |
| 602 | 602 | Bedroom double | Top right pane failed |
| 628 | 628 | Bedroom double | Bottom right pane failed |
| 632 | 638 | Bulkhead door | Opened (all the way) |
| 648 | 648 | Bedroom double | Top left pane failed |
| | 671 | Bedroom single | Failed |
| 877 | 879 | Bedroom single | WCD deployed |
| 959 | 1008 | Living room window | Manually vented |
| 1326 | 1326 | Experiment completed | |

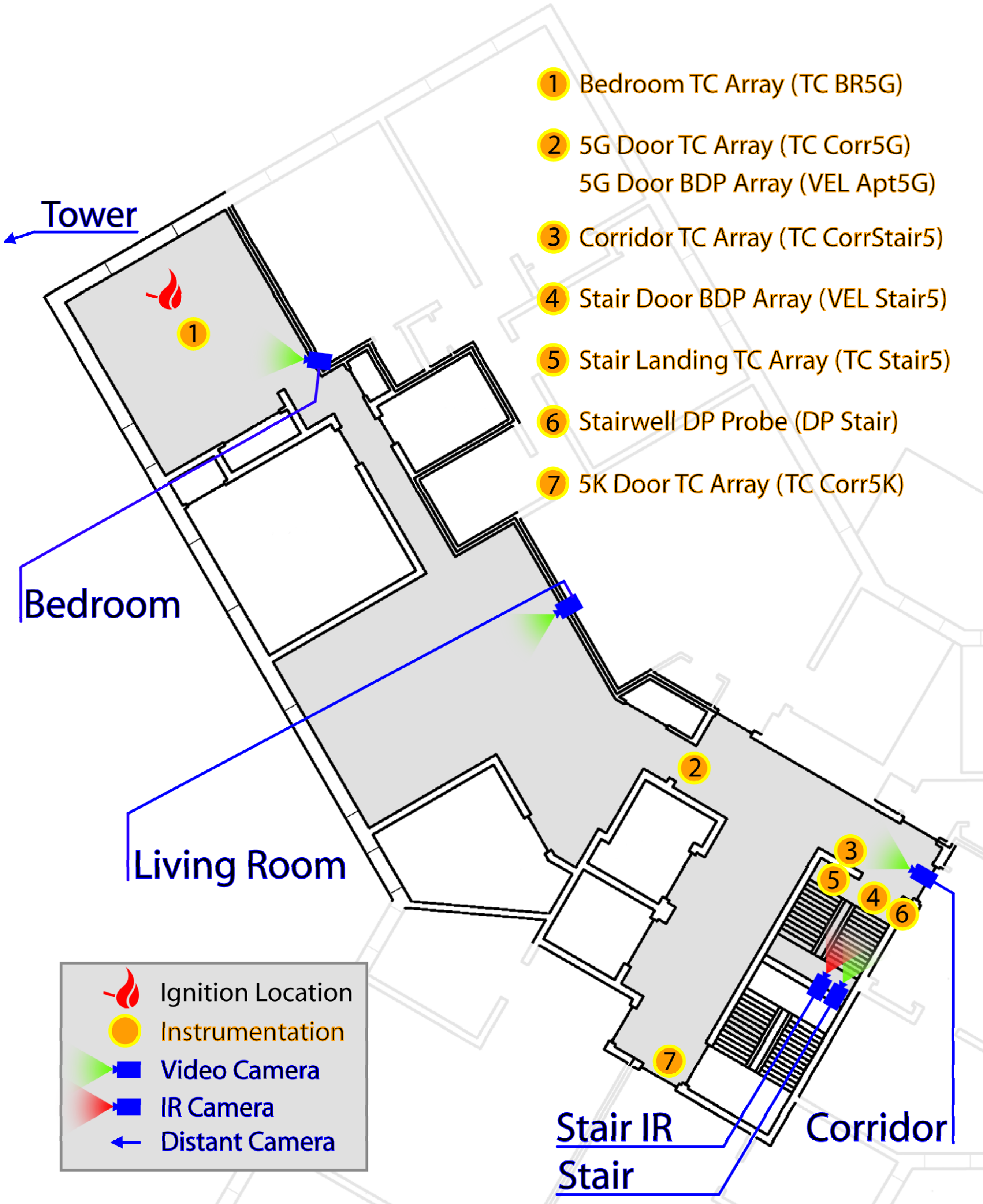



**Figure 3.10-2. Instrumentation and camera locations with labels.**

### 3.10.1 Observations

The observations are presented as a series of images captured from eight camera locations, seven were video cameras and one was a thermal imaging camera. The camera positions inside the building are shown in Figure 3.10-2.

Figure 3.10-3 through Figure 3.10-12 present sets of eight images one from each camera position, at a given time, from the time of ignition to 28 min (1680 s) after ignition. Images were captured every 4 min and at times when events had taken place that demonstrate the experimental objectives. Each image view is labeled. The first view (BEDROOM) at the top left of each figure shows the bedroom of apartment 5G, the bedroom furthest from the apartment entrance with a view of the single window straight across, double window to the right and ignition trashcan at the foot of the bed. The top right view (LIVINGRM) was of the living room looking across to the windows. The corridor view (CORRIDOR) shows the corridor leading up to the open apartment doorway. Next to that, the outside lobby view (LOBBY) shows the area just outside the lobby doors. The next two views (STAIR and STAIR IR) show the stairwell with a visual and a thermal imaging camera from the floor below the fire looking up to the fire floor. The bottom left view (ROOF) shows the bulkhead door at the top of the stairwell, this view is disconnected shortly after ignition. The bottom, right view (OUTSIDE) shows an external view of the fire apartment.

Figure 3.10-3 shows the images at the time of ignition. At this point, the seven video views were clear and unobstructed. However, the thermal image provided limited thermal contrast because the surfaces in the view are at nearly equal temperature. The damage to the corridor and stairwell from Experiment 5K can be seen as the existing condition in these areas.

Figure 3.10-4 shows the images at 240 s (4 min) after ignition. The fire ignited in the trash container at the base of the bed has just spread to the comforter and sheets on the bed. The smoke layer in the ignition bedroom has descended to about 0.9 m (3 ft) above the floor. The smoke in the living room or corridor was light in color and not very dense. At this point the roof view had malfunctioned and was lost for the remainder of this experiment.

Figure 3.10-5 shows the images at 480 s (8 min) after ignition. The lower left pane of the bedroom double window had failed 55 s prior. Smoke had filled the bedroom, living room, and corridor reducing the visibility in those views to nearly zero. Smoke which was leaking past the 5$^{th}$ floor stair A door was descending the stairwell.

Figure 3.10-6 shows the images at 550 s (9 min and 10 s) after ignition. The stairwell door on the 5$^{th}$ floor was opened and visibility in the stairwell on the floor below the fire was reduced further. Heat was also flowing down the stairwell as seen in the thermal imaging view. The lobby doors were opened 44 s prior creating a flow path down the stairwell. No flames are visible from the Tower View and the bedroom camera has been obscured by soot.

Figure 3.10-7 shows the images at 575 s (9 min and 35 s) after ignition. Flames were now visible in the living room and smoke was flowing out of the lobby doors. Flames were visible from the corridor and the density of the smoke in the stairwell was decreasing. There was still only one failed window pane in the bedroom so the fire was still growing after being cooled initially by the introduction of cold air from the outside.

Figure 3.10-8 shows the images at 630 s (10 min and 30 s) after ignition. The remainder of the bedroom double window's panes had failed and flames were pulsing back out toward the simulated wind. Visibility worsened in the corridor and stairwell and more heat was being forced down the stairwell. The amount of smoke coming out of the lobby from the stairwell was increasing.

Figure 3.10-9 shows the images at 720 s (12 min) after ignition. The bulkhead door had been opened completely 82 s prior. Smoke density in the stairwell was noticeably reduced. Flames were no longer pushing from the bedroom double window. Smoke was still coming out of the lobby and the thermal imaging camera had malfunctioned due to extreme heat exposure.

Figure 3.10-10 shows the images at 885 s (14 min and 45 s) after ignition. A WCD was deployed over the bedroom single window to prevent the loss of wind flow through that window and create worse conditions downstream in the structure. Visibility was beginning to return to the living room and no flames were visible. Flames were pulsing out of the bedroom double window again.

Figure 3.10-11 shows the images at 960 s (16 min) after ignition. Smoke density in the stairwell had decreased noticeably from 80 s prior when the WCD was deployed over the bedroom single window indicating less burning and more flow moving up the stairwell. There was no longer smoke coming from the lobby doors.

Figure 3.10-12 shows the images at 1200 s (20 min) after ignition. The living room windows had been manually ventilated at 1008 s to see if there was any fire in the living room and to see if it would intensify. At this time there did not appear to be any fire in the living room. Smoke had largely cleared the stairwell at this point. Visibility in the corridor had also improved significantly. The tower view was temporarily disabled during this period.

Figure 3.10-3. Experiment 5G, ignition.


**Figure 3.10-4. Experiment 5G, 240s after ignition.**


Figure 3.10-5.  Experiment 5G, 480s after ignition.

**Figure 3.10-6. Experiment 5G, 550s after ignition.**

Figure 3.10-7. Experiment 5G, 575s after ignition.


**Figure 3.10-8. Experiment 5G, 630s after ignition.**

**Figure 3.10-9. Experiment 5G, 720s after ignition.**

Figure 3.10-10. Experiment 5G, 885s after ignition.

Figure 3.10-11. Experiment 5G, 960s after ignition.


Figure 3.10-12. Experiment 5G, 1200s after ignition.

### 3.10.2 Temperatures

Figure 3.10-13 through Figure 3.10-15 provide temperature data for five measurement locations on the fire floor at two elevations and throughout the height of the stairwell. The locations of the measurement points can be seen in Figure 3.10-2. The events that occurred during the experiment are listed on the top of the figures with lines at the time of the event. A time history for each thermocouple at each measurement location can be found in Appendix D – Detailed Graphs.

Figure 3.10-13 shows the temperatures versus time at 2.1 m (7 ft) above the floor at 5 measurement locations, the bedroom, just outside the fire apartment in the corridor, just outside Apartment 5K in the corridor, just outside the A stairwell doorway, and just inside the A stairwell on the landing. The temperature in the bedroom increased to above 300 ºC (572 ºF) and became ventilation limited. The temperature remained constant until the window began to fail. After the first pane failed the temperature increased to over 600 ºC (1112 ºF). The temperature decreased again and then climbed above 800 ºC (1472 ºF) with the fire floor stairwell door opened. The temperature in the bedroom remained above 700 ºC (1292 ºF) for the remainder of the experiment.

Corridor and stairwell temperatures at 2.1 m (7 ft) remained below 200 ºC (392 ºF) until the 5$^{th}$ floor stairwell door was opened and the temperatures increased to above 300 ºC (572 ºF). The corridor temperature peaked at approximately 450 ºC (842 ºF). A wind driven fire never fully developed and the temperatures decreased after 800 s because the fuel was burning down in the bedroom and the living room never ignited.

Figure 3.10-14 shows the temperatures at 1.2 m (4 ft) which would be more representative to where firefighters would be operating or occupants would be evacuating. The temperature in the bedroom at 1.2 m (4 ft) increased to approximately 250 ºC (482 ºF) and became ventilation limited. The temperature remained constant until the window began to fail. After the first pane failed the temperature increased to over 500 ºC (932 ºF). The temperature decreased again and then climbed above 800 ºC (1472 ºF) with the fire floor stairwell door opened. The bedroom transitioned to flashover and the temperatures at every elevation remained above 700 ºC (1292 ºF) for the remainder of the experiment.

Corridor and stairwell temperatures at 1.2 m (4 ft) remained below 200 ºC (392 ºF) until the 5$^{th}$ floor stairwell door was opened and the temperatures increased to above 300 ºC (572 ºF). The corridor temperature tracked with the 2.1 m (7 ft) elevation for the remainder of the experiment, while the wind was flowing into the bedroom creating a well mixed flow and no lower layer.

Figure 3.10-15 shows the temperatures 1.2 m (4 ft) above the landing on floors 1, 2, 4, 6 and at the landing above the 7$^{th}$ floor with access to the roof. After the fire floor stairwell door was opened the temperature on the landing above and below the fire floor increased to over 200 ºC (392 ºF). Once the bulkhead door was opened the temperature below the fire floor decreased and the temperature above the fire floor increased to 340 ºC (644 ºF) and the temperature at the top of the stairwell increased to 250 ºC (482 ºF).

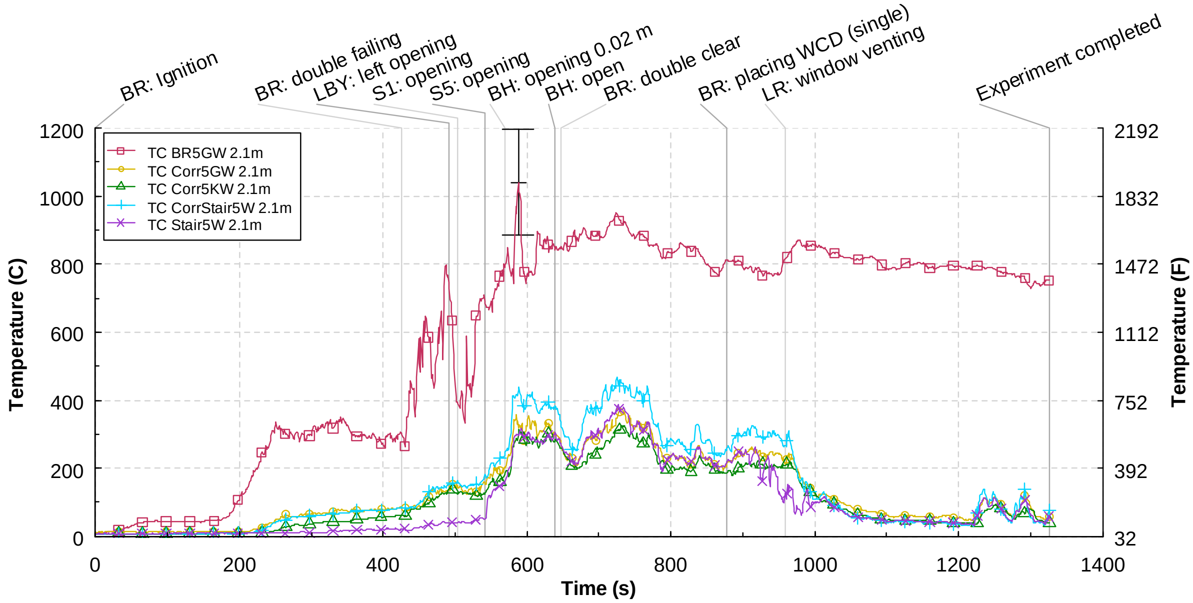



**Figure 3.10-13. 5G Temperature vs. time at 2.1 m above the floor**

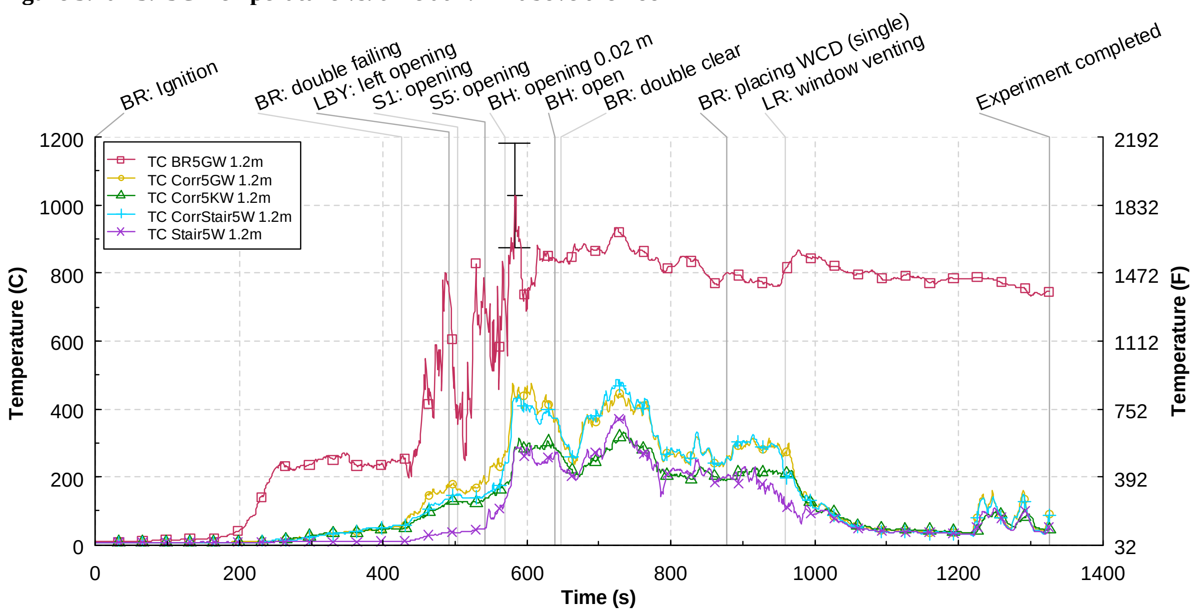



**Figure 3.10-14. 5G Temperature vs. time at 1.2 m above the floor**

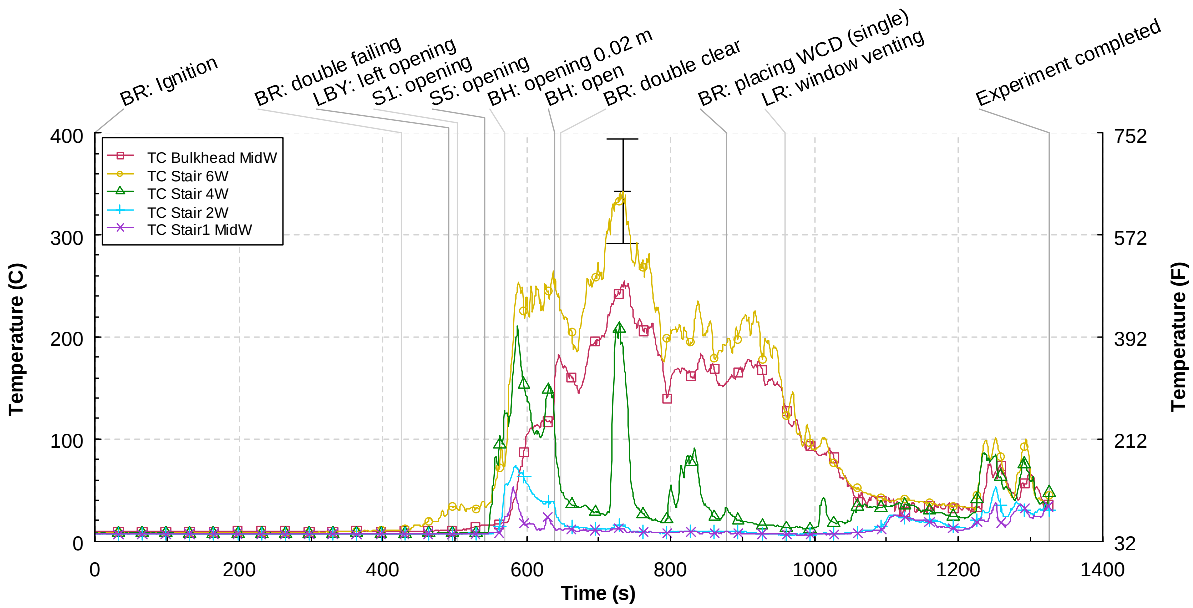



**Figure 3.10-15. 5G stairwell temperature vs. time**

### 3.10.3 Pressures

Average pressure measurements in the stairwell are shown in Figure 3.10-16. The differential pressure measurements were made at 1.2 m (4 ft) on the stairwell landing of every floor and referenced to an apartment on the same floor. With all of the doors to the stairwell closed the pressures remained below 8 Pa and only fluctuated slightly. When the window in the fire room failed the pressures in the stairwell increased slightly due to the leaks around the fire floor door. After the fire floor door was opened the pressure in the top of the stairwell increased to as high as 68 Pa at the top of the stairwell and approximately 50 Pa in the area of the fire floor. Pressures below the 4$^{th}$ floor remained below 20 Pa due to the 1$^{st}$ floor door being opened. The bulkhead door was opened at 635 s and the pressures decreased to below 10 Pa with the exception of the fire floor.

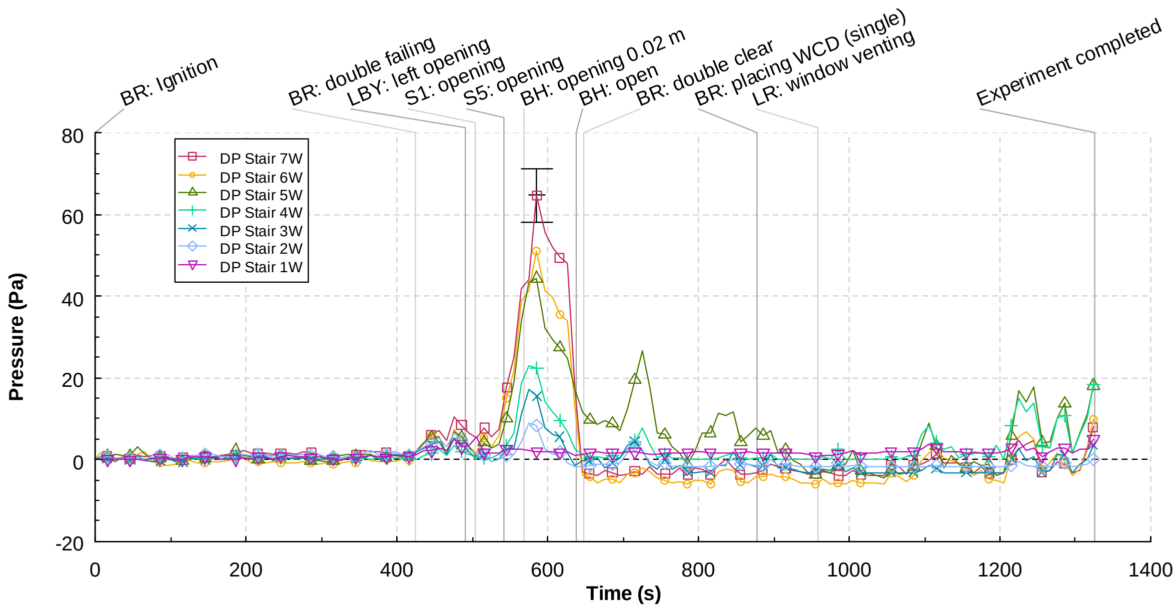



**Figure 3.10-16. 5G stairwell pressures vs. time**

### 3.10.4 Velocities

Average doorway velocities from 4 doors; the fire apartment door, the door from the fire floor to the stairwell, the door at the base of the stair and the door at the bulkhead, were recorded versus time and shown in Figure 3.10-17. The three bi-direction probes in each door were averaged to provide the bulk flow through the doors. A time history for each probe at each measurement location is located in Appendix D – Detailed Graphs.

Velocities out of the fire apartment and into the corridor were approximately 1 m/s (2 mph) after the windows failed and increased to 3 m/s (7 mph) with the fire floor door open and increased further to approximately 7 m/s (16 mph) after the bulkhead door was opened. Flows out of the bulkhead door reached 10 m/s (22 mph) at the peak and bulk flows into the 1st floor stairwell door were approximately 1 m/s (2.2 mph).

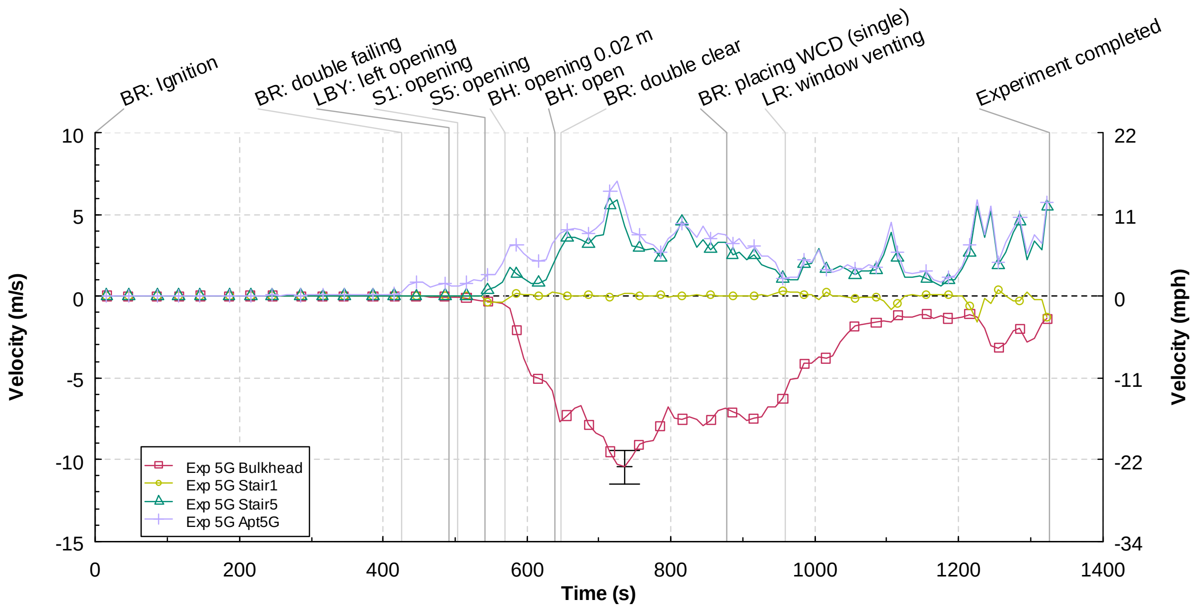



**Figure 3.10-17. 5G Velocities vs. time**

## 3.10.5 Discussion

This experiment began in a similar way to many of the others, with a growing fire in the bedroom that became ventilation limited until the window failed. The difference in this experiment was that a fully developed wind driven condition was never created and the fire ran out of fuel before flames could be forced into the corridor. A possible reason for this could be that the single window in the bedroom failed allowing a loss of flow and more burning locally to consume the fuel faster. The source of wind was directed at the bedroom double window and when the single window failed that became the path of least resistance. There was more flow entering the room than could leave out the single window so flow did force hot gases into the corridor and hallway but flames being forced into the living room from floor to ceiling did not occur. Flames temporarily were forced into the living room, but nothing was ignited. A WCD was deployed to block the loss of flow out of the single window, but by that time in the experiment, there was not enough fuel remaining in the bedroom to generate the energy and conditions for flashover.

While a fully developed wind driven condition was not achieved a possible tactic was highlighted. If it can be determined from the team above the fire apartment that the wind is only subjected to one side of the fire room and there is a second window on the downwind side of the fire room that has not self ventilated then manually ventilating that window could reduce the impact of the wind down stream by providing a low pressure relief locally to the fire. Another vent should not be made on the upwind side or if it is suspected that the wind could shift, because this could lead to additional wind pushing into the fire room, which could add to the wind driven fire flows in the structure.

The first pane of the bedroom window failed at 425 s and the window completely failed at 648 s. The temperature in the center of the bedroom at 1.2 m (4 ft) at the time of window failure was approximately 240 ºC (464 ºF). The temperature in the center of the room at the time of complete window failure was in excess of 800 ºC (1472 ºF). This demonstrates that when a portion of the window fails the wind being introduced through the opening cools and slows the failure of the rest of the window. The majority of the window did not fail until the room transitioned to flashover. The single window in the room failed at 671 s when the room temperature was approximately 850 ºC (1562 ºF).

Once again during this experiment the fire could not grow until a ventilation path was created. When the flow path was made to go down the stairs and out the 1st floor the fire grew but did so slowly. When the path was transitioned to travel up the stairs and out of the bulkhead the fire peaked but had run low on fuel. The hot gases traveled past the living room but did not ignite it because of lack of oxygen in the living room and lack of a flow path toward the living room windows. When the living room window was manually ventilated to try to flow past the sofas the fire in the bedroom had already burned down and would not spread.

## 3.11 Experiment 5G2

The eleventh experiment in the structure was located in the same apartment as the tenth experiment, 5G. Experiment 5G2 was ignited in the living room on the top of sofa that backed to the bedroom (Figure 3.11-1). The fire in the bedroom did not extend beyond the room of origin so the apartment was cleared of smoke and the experiment was ignited. Both windows in the back bedroom had failed in the previous experiment so they remained open during this experiment. The living room window was also manually ventilated during the previous experiment so this experiment began with the window open. This experiment also utilized a simulated wind provided by the MVU. The simulated wind was subjected into the living room window at a magnitude of approximately 9 m/s to 11 m/s (20 mph to 25 mph). The events that took place during the experiment to accomplish the experimental objectives below are shown in Table 3.11-1.

Experimental Objectives

- Create wind driven fire conditions from a living room fire
- Examine building flows with different door opening configurations
- Examine impact of the deployment of a WCD on fire room window
- Utilize portable PPV fans to control smoke movement
- Control wind driven conditions with FBN in conjunction with WCD

The results for the experiment are presented in the following sections: observations, temperature, pressure, velocity, and discussion. Figure 3.11-2 shows the camera names and locations used in the observation section and the instrumentation names and locations used in the temperature, pressure and velocity sections.

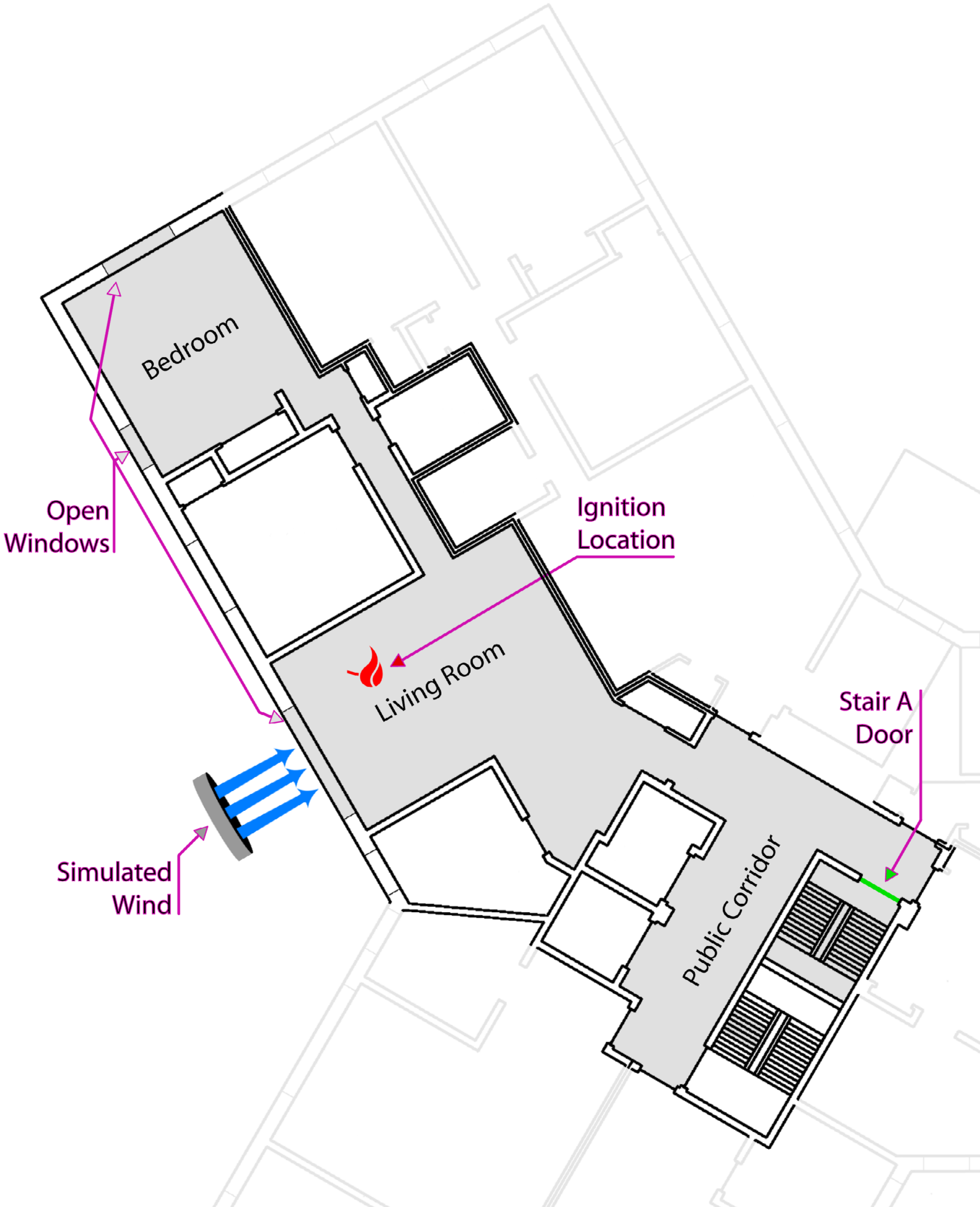



**Figure 3.11-1. 5th floor apartment G floor plan with locations pertinent to Experiment 5G2**

**Table 3.11-1: Experiment 5G2 Timeline**

| Start (s) | End (s) | Event Location | Event Description |
|---|---|---|---|
| 0 | 0 | Living room | Ignition (window vented) |
| 39 | 44 | 1st floor stair A | 27 inch fan deactivated |
| 177 | 187 | 5th floor stair A | Door closed |
| 518 | 521 | 5th floor stair A | Door opened |
| 543 | 547 | Bulkhead door | Opened |
| 687 | 706 | Living room window | WCD deployed |
| 746 | 748 | Front lobby | 2 - 27 inch fans activated |
| 801 | 803 | Living room window | WCD pulled back at bottom right |
| 819 | 825 | Bulkhead door | Closed |
| 823 | 834 | Living room window | FBN 2 inserted, bottom right replaced |
| 879 | 879 | Living room window | FBN 2 started flowing water (fog) |
| 932 | 932 | Living room window | FBN 2 stopped |
| 933 | 944 | Living room window | WCD pulled back at bottom right |
| 953 | 953 | Living room window | FBN 2 started flowing water (fog) |
| 978 | 978 | Living room window | FBN 2 stopped |
| 1084 | 1085 | Living room window | WCD replaced |
| 1125 | 1157 | Front lobby | One 27 inch fan moved inside |
| 1138 | 1141 | Front lobby | Right door opened |
| 1172 | 1175 | Front lobby | Right door closed |
| 1350 | 1350 | Experiment completed | |

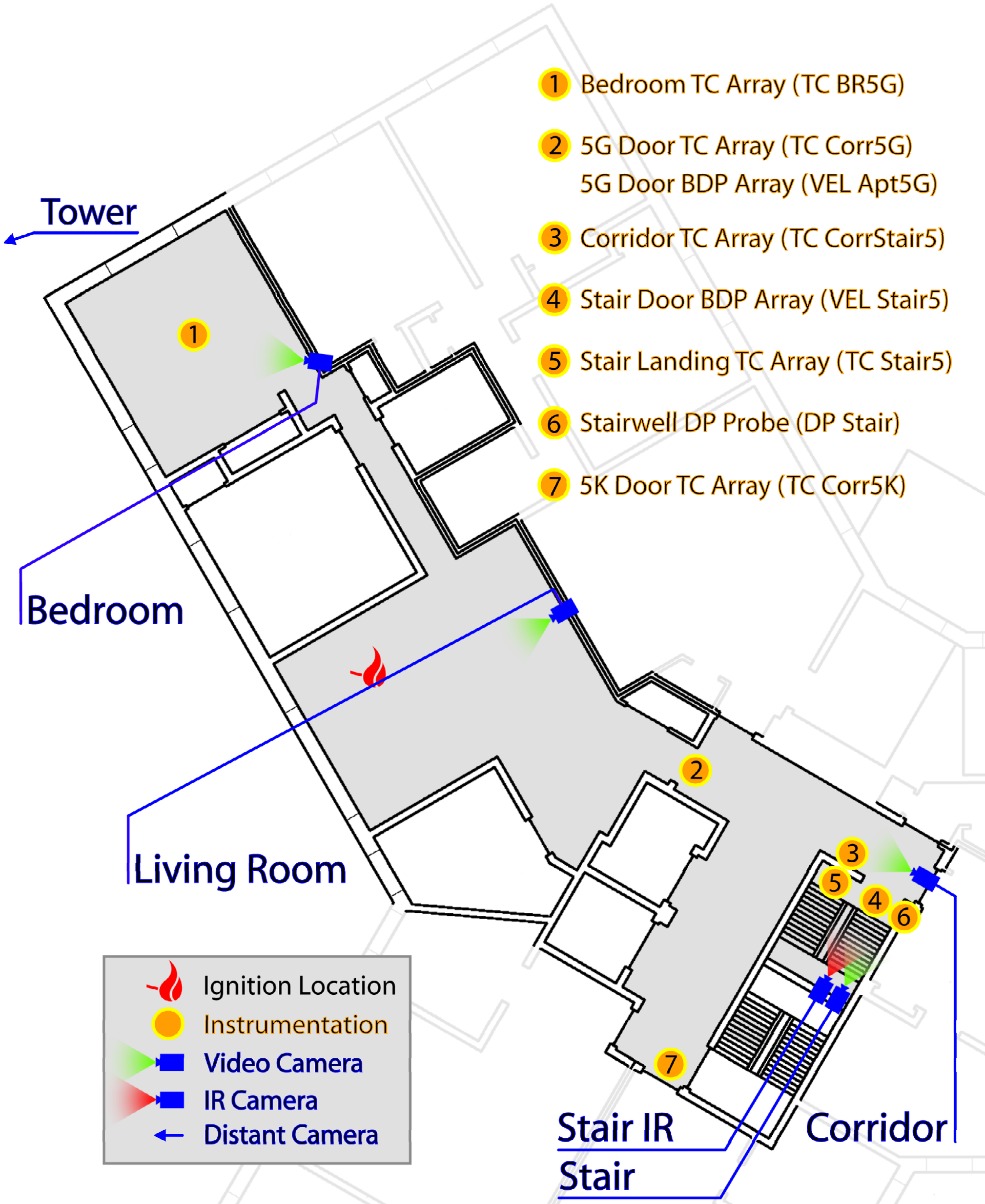



**Figure 3.11-2. Instrumentation and camera locations with labels.**

### 3.11.1 Observations

The observations are presented as a series of images captured from eight camera locations, seven were video cameras and one was a thermal imaging camera. The camera positions inside the building are shown in Figure 3.11-2.

Figure 3.11-3 through Figure 3.11-15 present sets of eight images one from each camera position, at a given time, from the time of ignition to 28 min (1680 s) after ignition. Images were captured every 4 min and at times when events had taken place that demonstrate the experimental objectives. Each image view is labeled. The first view (BEDROOM) at the top left of each figure shows the bedroom of apartment 5G, the bedroom furthest from the apartment entrance with a view of the single window straight across, double window to the right and ignition trashcan at the foot of the bed. The top right view (LIVINGRM) was of the living room looking across to the windows. The corridor view (CORRIDOR) shows the corridor leading up to the open apartment doorway. Next to that, the outside lobby view (LOBBY) shows the area just outside the lobby doors. The next two views (STAIR and STAIR IR) show the stairwell with a visual and a thermal imaging camera from the floor below the fire looking up to the fire floor. The bottom left view (ROOF) shows the bulkhead door at the top of the stairwell, this view is disconnected shortly after ignition. The bottom, right view (OUTSIDE) shows an external view of the fire apartment.

Figure 3.11-3 shows the images at the time of ignition. The bedroom and roof views were still missing from the previous experiment (experiment 5G). The living room window was vented in the previous experiment. The firefighters in the corridor view were performing a remote ignition of the living room and retreated from that area shortly after.

Figure 3.11-4 shows the images at 240 s (4 min) after ignition. At this point the sofa where ignition occurred was mostly involved in flames, and those flames were visible from the corridor view, which looks directly into the living room area through the apartment entrance. While there was no visible smoke layer, the amount of smoke in the living room, stairwell, and corridor had increased noticeably.

Figure 3.11-5 shows the images at 480 s (8 min) after ignition. At this point the sofa which provided the ignition location in the living room was fully involved. Visibility in the corridor has reduced to zero. Conditions in the stairwell had not changed noticeably from 240 s prior.

Figure 3.11-6 shows the images at 565 s (9 min and 25 s) after ignition. The living room was transitioning to flashover and flames were beginning to spread into the corridor. High heat conditions have made it to the open stairwell and smoke was exiting the front lobby doors. The bulkhead door was opened 18 s earlier.

Figure 3.11-7 shows the images at 695 s (11 min and 35 s) after ignition. The WCD deployment began over the living room window 8 s prior to this image. The view in the living room and corridor was darkened down due to under-ventilated conditions. Visibility in the stairwell was zero and heat was still visible coming down the stairs.

Figure 3.11-8 shows the images at 720 s (12 min) after ignition. At this point the corridor camera view was lost for the remainder of the test. Significant volumes of smoke were venting down the stairwell and out the open lobby doors. The conditions in the stairwell remained the same from the previous set of images.

Figure 3.11-9 shows the images at 820 s (13 min and 40 s) after ignition. This image showed the WCD being pulled back so that the FBN 2 could be inserted from below. Flames were visible in the living room and conditions in the stairwell were still poor. Two PPV fans were operating outside the lobby doors. Shortly after this image the WCD was placed back into place to cover the FBN 2.

Figure 3.11-10 shows the images at 945 s (15 min and 45 s) after ignition. The FBN 2 with a fog nozzle was flowed into the living room for 53 s and then the WCD was pulled back to observe its effectiveness. There were no longer flames visible from the outside or inside views. There was no longer smoke coming out of the lobby doors and the stairwell view was not clear but could be obscured by soot deposited on the lens of the camera.

Figure 3.11-11 shows the images at 960 s (16 min) after ignition. At this point conditions had not changed significantly from 15 s prior. The FBN 2 was flowed again with the WCD pulled back to further extinguish the fire. Some steam was coming out of the living room and conditions in the stairwell were improved.

Figure 3.11-12 shows the images at 1200 s (20 min) after ignition. The fire in the living room was largely extinguished, and visibility had returned to all of the remaining views. One PPV fan was moved inside to the 1st floor doorway. It was activated 44 s prior and the visibility in the stairwell improved.

**Figure 3.11-3. Experiment 5G2, ignition.**

Figure 3.11-4. Experiment 5G2, 240s after ignition.

**Figure 3.11-5. Experiment 5G2, 480s after ignition.**

Figure 3.11-6. Experiment 5G2, 565s after ignition.

Figure 3.11-7. Experiment 5G2, 695s after ignition.

Figure 3.11-8.  Experiment 5G2, 720s after ignition.

Figure 3.11-9. Experiment 5G2, 820s after ignition.

Figure 3.11-10. Experiment 5G2, 945s after ignition.

Figure 3.11-11. Experiment 5G2, 960s after ignition.


Figure 3.11-12. Experiment 5G2, 1200s after ignition.

### 3.11.2 Temperatures

Figure 3.11-13 through Figure 3.11-15 provide temperature data for four measurement locations on the fire floor at two elevations and throughout the height of the stairwell. The locations of the measurement points can be seen in Figure 3.11-2. The events that occurred during the experiment are listed on the top of the figures with lines at the time of the event. A time history for each thermocouple at each measurement location is located in Appendix D – Detailed Graphs.

Figure 3.11-13 shows the temperatures versus time at 2.1 m (7 ft) above the floor at 4 measurement locations; just outside the fire apartment in the corridor, just outside Apartment 7K in the corridor, just outside the A stairwell doorway, and just inside the A stairwell on the landing. The temperatures in the hallway increased as the fire in the living room increased. The fire transitioned to flashover at approximately 565 s, 30 s after the bulkhead door was opened. Shortly after this time the temperatures in the flow path increased from 250 ºC (482 ºF) to over 600 ºC (1112 ºF) in seconds. The temperature in the corridor peaked at 800 ºC (1472 ºF) and decreased to just over 600 ºC (1112 ºF) before the WCD was deployed. The WCD maintained temperatures below 600 ºC (1112 ºF) by eliminating the wind but air was still available to the fire from the open bedroom windows. Temperatures dropped further when the FBN was directed into the living room. The water decreased the temperature to below 300 ºC (572 ºF) in less than 1 min of flowing.

Figure 3.11-14 shows the temperatures at 1.2 m (4 ft) which would be more representative to where firefighters would be operating or occupants would be evacuating. These temperatures were almost identical to the 2.1 m (7 ft) measurements because the wind was flowing into the apartment for the duration of the experiment. The wind was mixing all the gases and there was no layering in the corridor or stairwell.

Figure 3.11-15 shows the temperatures 1.2 m (4 ft) above the landing on floors 1, 2, 4, 6 and at the bulkhead. After the 5$^{th}$ floor stairwell door was opened there was a rush of heat into the stairwell, including increases in temperature all the way down to the lobby of 100 ºC (212 ºF). The bulkhead door was opened 16 s later and the flow transitioned to up the stairwell strictly. Temperatures as high as 600 ºC (1112 ºF) were measured at the floor above the fire and the bulkhead temperature peaked at approximately 400 ºC (752 ºF). The WCD maintained stairwell temperatures below 500 ºC (932 ºF) and the FBN decreased the temperatures to less than 200 ºC (392 ºF) quickly. The combination of these tactics would allow a fire fighting crew to advance to the fire apartment.

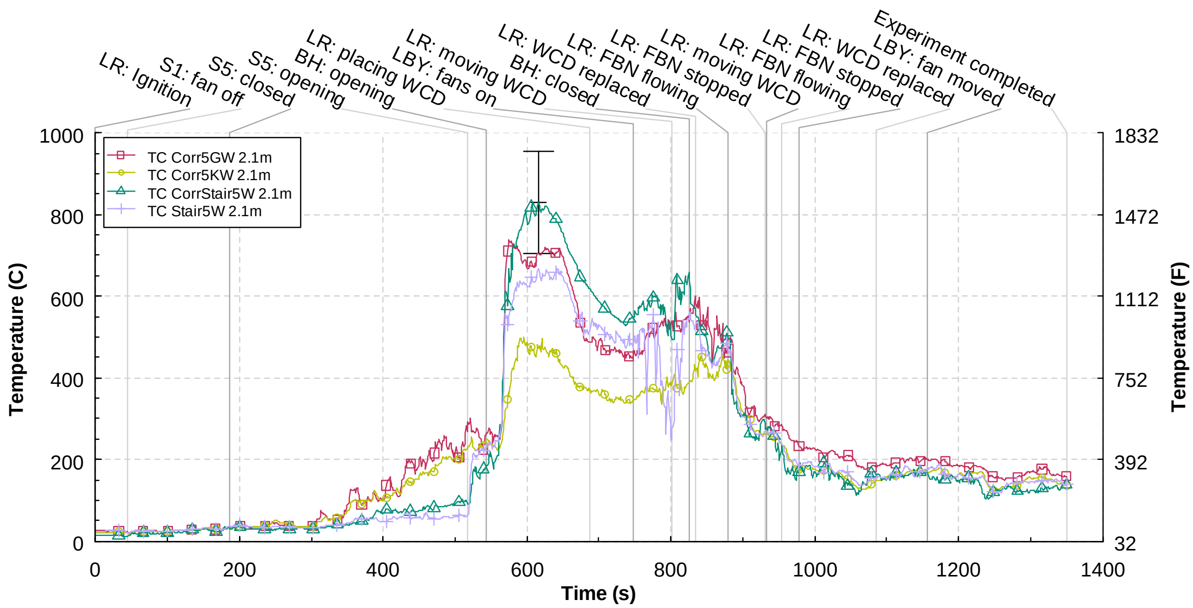



**Figure 3.11-13. 5G2 Temperature vs. time at 2.1 m above the floor**

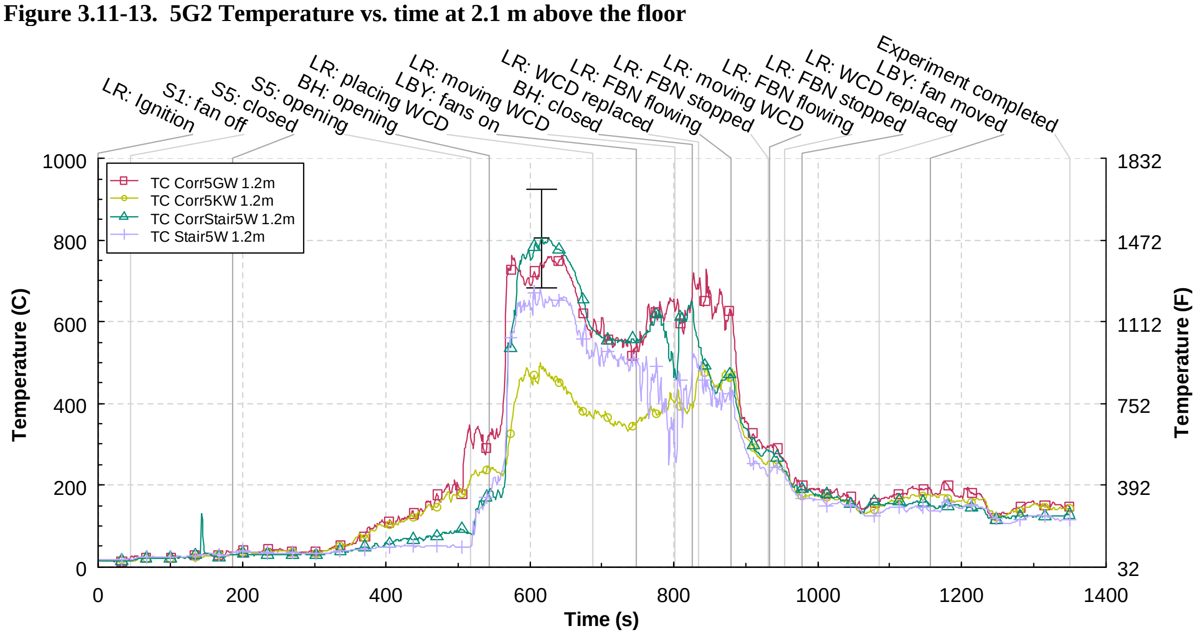



**Figure 3.11-14. 5G2 Temperature vs. time at 1.2 m above the floor**

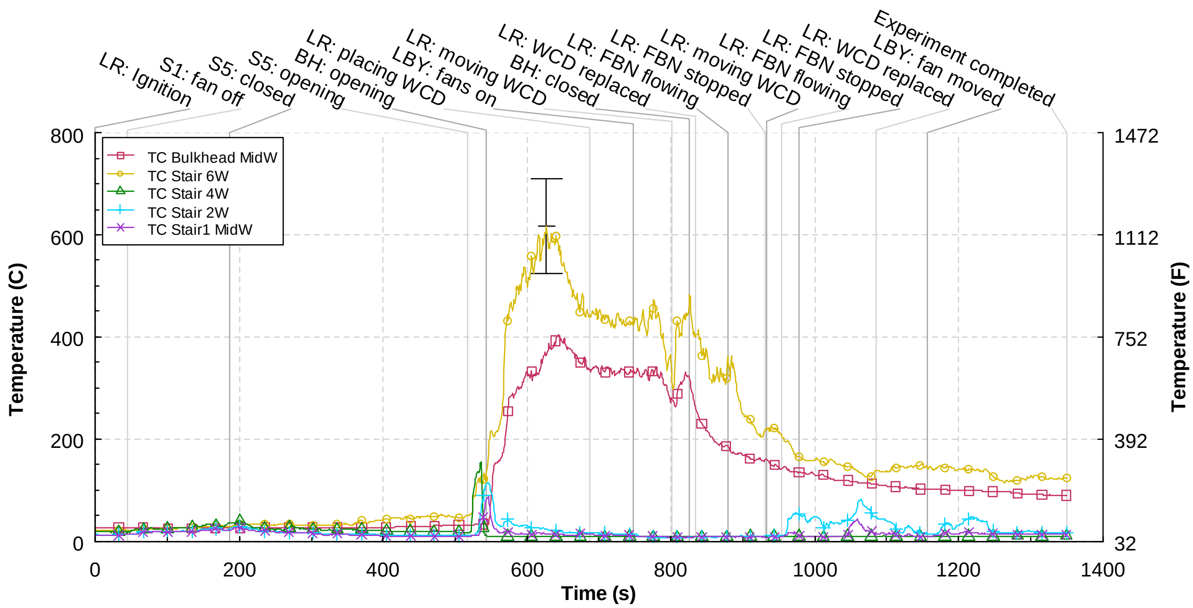



**Figure 3.11-15. 5G2 stairwell temperature vs. time**

### 3.11.3 Pressures

Average pressure measurements in the stairwell are shown in Figure 3.11-16. The differential pressure measurements were made at 1.2 m (4 ft) on the stairwell landing of every floor and referenced to an apartment on the same floor. The wind was subjected to the fire apartment from ignition time on so there was no ambient pressure. The initial pressures were 20 Pa to 40 Pa at the top of the stairwell and 0 Pa to 20 Pa in the lower portion of the stairwell with the fire floor door open and the 1$^{st}$ floor stair door open. When the 5$^{th}$ floor door was closed the pressures all dropped below 20 Pa. Opening the fire floor door again when the fire was growing increased the pressures to as high as 60 Pa. The pressures dropped again when the bulkhead door was opened 16 s later. Pressures remained low until the WCD was pulled back for the nozzle and the PPV fans were turned on. Pressures reached as high as 80 Pa with the effects of the fire, wind and fans.

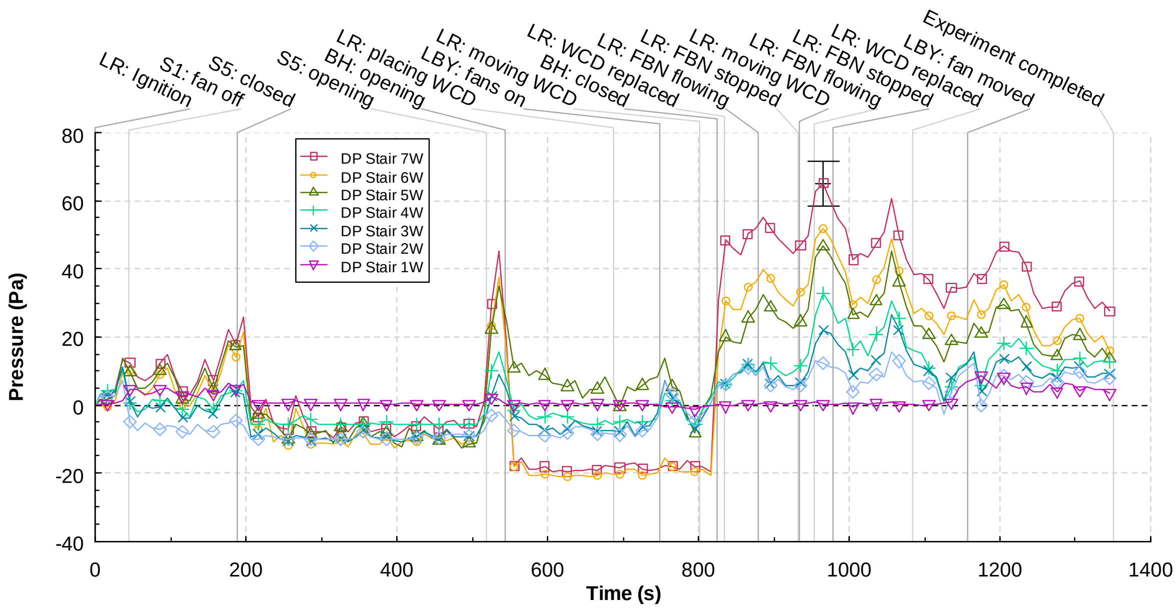



**Figure 3.11-16. 5G2 stairwell pressures vs. time**

### 3.11.4 Velocities

Average doorway velocities from 3 doors; the fire apartment door, the door from the fire floor to the stairwell and the door at the base of the stair, were recorded versus time and shown in Figure 3.11-17. The three bi-direction probes in each door were averaged to provide the bulk flow through the doors. A time history for each probe at each measurement location is located in Appendix D – Detailed Graphs.

The initial velocities while the fire was growing were approximately 3 m/s (7 mph) into the fire apartment and down the stairwell to the first floor. This bulk velocity decreased to less than 1 m/s (2 mph) when the stairwell was closed. The peak velocity out of the fire apartment and into the stairwell was approximately 7 m/s (16 mph) when the fire was at its peak and the stair and bulkhead doors were open. Deploying the WCD slowed the velocity and suppressing the fire decreased the velocity to less than 2 m/s (4 mph).

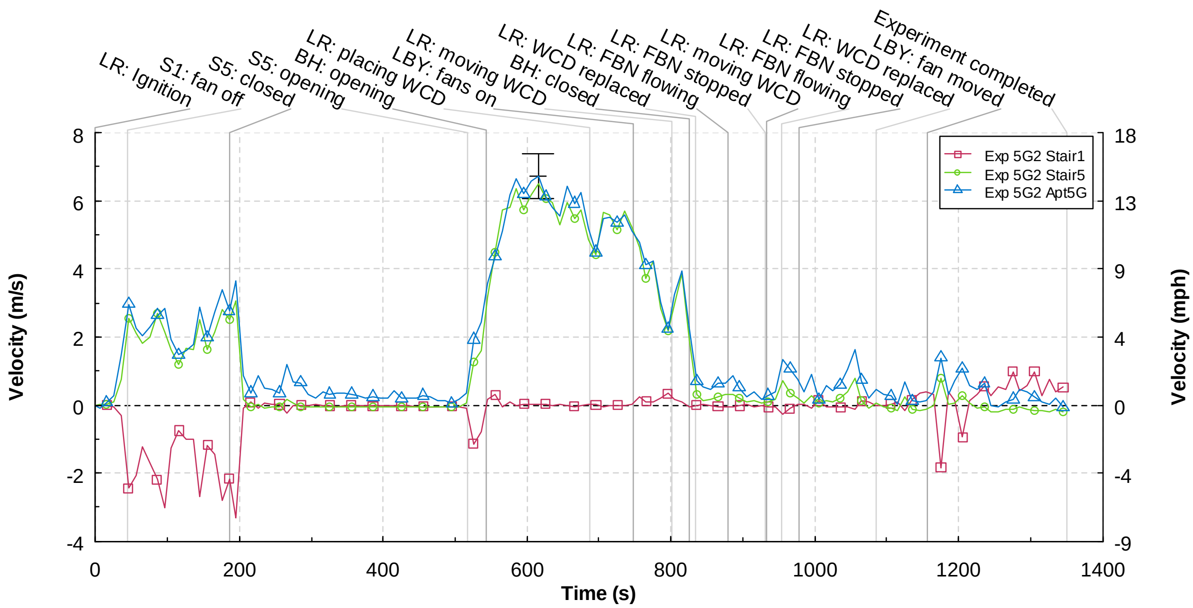



**Figure 3.11-17. 5G2 Velocities vs. time**

### 3.11.5 Discussion

Wind driven fire conditions were created utilizing the simulated wind from the MVU. Flames entered the corridor and temperatures in the stairwell exceeded 600 ºC (1112 ºF). Large amounts of smoke were forced out of the front lobby door displaying untenable conditions throughout the entire stairwell. The condition created during this experiment were not conducive to a direct frontal fire attack and firefighters remote from the fire in the stairwell would have been threatened if they were in the flow path due to extreme temperatures.

The wind was able to flow into the living room through the open door so the fire had to grow with cool air moving past it, which it was able to do. As in many of the experiments, the fire did not grow quickly when the flow path was down the stairs but transitioned quickly when the bulkhead door was opened. The fire transitioned to flashover and failed to result in a wind driven condition. The hot gases were primarily being forced to the stairwell and up the stairs to the open bulkhead door. Once the WCD was deployed the conditions changed. The flow was stopped but the fire still was able to burn because of the air available from the open windows in the bedrooms and the open stairwell. The fire floor door is a key door to control to limit the impact to the rest of the structure. With this door open all floors were threatened with untenable conditions for firefighters and occupants.

The WCD was effective at minimizing the impact of the wind, but in this scenario there was still plenty of oxygen available to the fire from the opening made from the previous experiment. The WCD relies on limiting the oxygen to slow the burning and lower the temperatures. The WCD held up well to extreme temperature above 500 ºC (932 ºF) for more than 150 s. The WCD was also controlled by the crew to be able to pull a corner of the WCD away to insert the FBN. At one point, the WCD was wrapped around the FBN, but that was fixed by the deployment crews.

The PPV fans were activated to push the smoke up the stairwell once the WCD was deployed. The fans were effective when the wind was blocked but were less effective when the WCD was pulled back for the nozzle to be inserted. The fans just don't increase the pressure enough to stop the higher flow from the wind. Stairwell temperatures in the area of the fire floor decreased by over 200 ºC (392 ºF) when the fans were activated and the WCD was in place. After the fire was suppressed the fans did a good job of keeping the smoke out of the stair, even with a little wind effect.

The FBN 2 with a fog nozzle was flowed at approximately 160 gpm for 60 s. The fire in the living room was suppressed but not extinguished. The temperature in the corridor decreased significantly from above 600 ºC (1112 ºF) to under 300 ºC (572 ºF) in seconds. The FBN performed well in conjunction with the WCD but this was very labor intensive and required practice by the crews involved to execute properly.

## 3.12 Experiment 3E

The twelfth experiment in the structure was located on the 3rd floor in apartment 3E. Experiment 3E was ignited in both the bedroom and the living room in an effort have both rooms involved in fire simultaneously to examine the impact of a FBN deployed in the bedroom (Figure 3.11-1). This experiment also utilized a simulated wind provided by the MVU. The simulated wind was subjected to the bedroom window at a magnitude of approximately 9 m/s to 11 m/s (20 mph to 25 mph). The events that took place during the experiment to accomplish the experimental objectives below are shown in Table 3.12-1.

Experimental Objectives

- Create wind driven fire conditions from a bedroom and living room fire
- Examine window failure times and conditions
- Examine building flows with different door opening configurations
- Control wind driven conditions with FBN
- Examine use of an aerosol generation suppression device
- Utilize portable PPV fans to control smoke movement

The results for the experiment are presented in the following sections: observations, temperature, pressure, velocity, and discussion. Figure 3.11-2 shows the camera names and locations used in the observation section and the instrumentation names and locations used in the temperature, pressure and velocity sections.

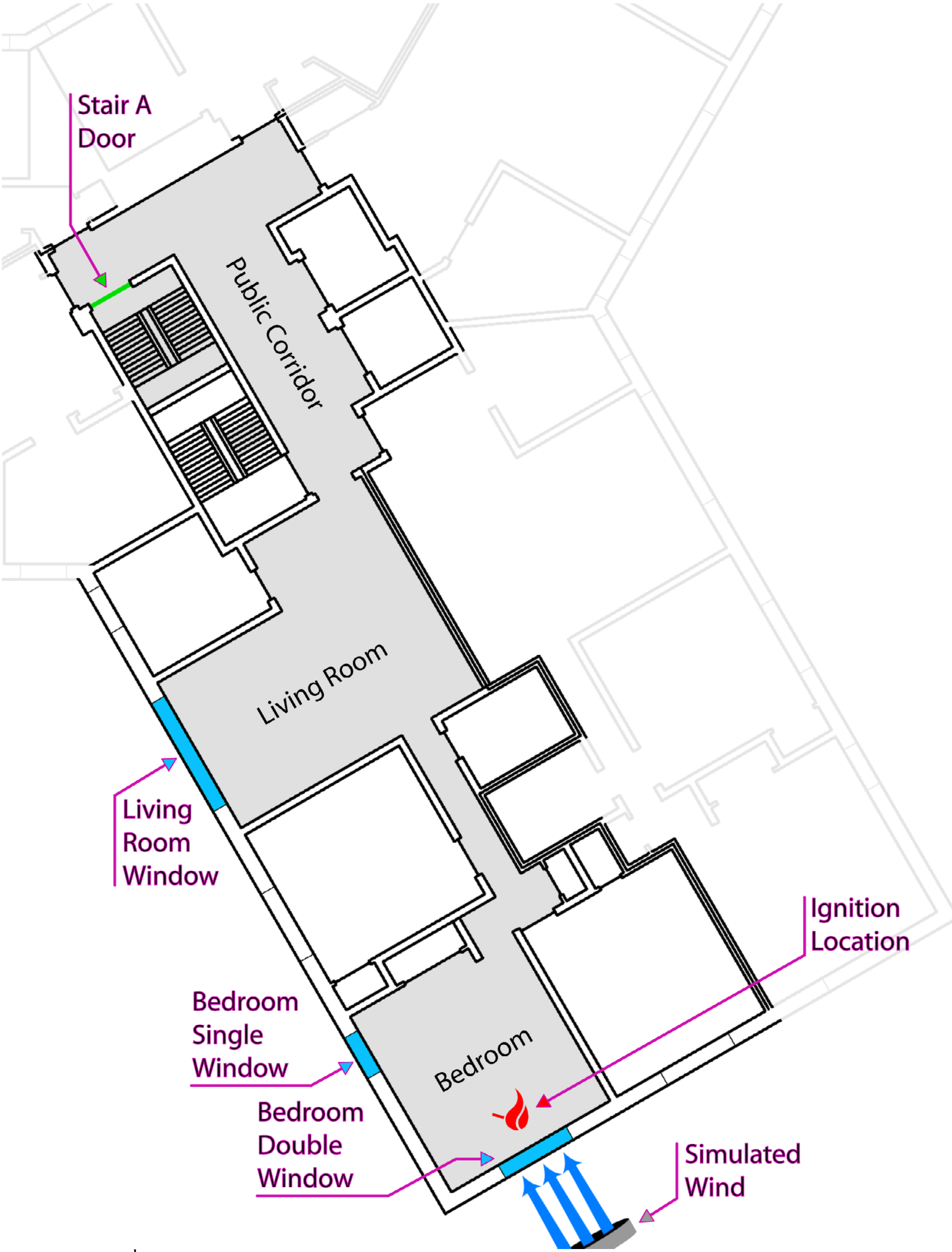



**Figure 3.12-1. 3rd floor apartment E floor plan with locations pertinent to Experiment 3E**

**Table 3.12-1: Experiment 3E Timeline**

| Start (s) | End (s) | Event Location | Event Description |
|---|---|---|---|
| 0 | 0 | Bedroom and living room | Ignition |
| 272 | 274 | Front lobby | Doors opened |
| 300 | 303 | 1st floor stair A | Door opened |
| 318 | 324 | 3rd floor stair A | Door opened |
| 379 | 383 | Bulkhead door | Opened |
| 493 | 494 | Bedroom double | Bottom right pane failed |
| 500 | 501 | Bedroom double | Top right pane failed |
| 525 | 526 | Bedroom double | Top left pane failed |
| 632 | 632 | Bedroom double | Bottom left pane failed |
| 943 | 943 | Bedroom double | FBN 2 started flowing (Smooth Bore) |
| 1017 | 1017 | Bedroom double | FBN 2 stopped |
| 1094 | 1097 | Living room window | Center pane vented manually |
| 1264 | 1264 | Living room window | Top right pane failed |
| 1301 | 1301 | Bedroom double | FBN 2 started flowing (Smooth Bore) |
| 1347 | 1348 | Bedroom double | FBN 2 stopped |
| 1362 | 1362 | Living room window | Aearosol generating device activated |
| 1368 | 1403 | Living room window | WCD deploying |
| 1513 | 1517 | Living room window | WCD removed |
| 1551 | 1554 | Bulkhead door | Closed |
| 1648 | 1680 | 1st floor stair A | 27 inch fan on |
| 1653 | 1678 | Front lobby | 2 - 27 inch fans activated |
| 2155 | 2156 | Living room window | FBN 1 started flowing (Smooth Bore) |
| 2175 | 2175 | Living room window | FBN 1 stopped |
| 2298 | 2298 | Experiment completed | |

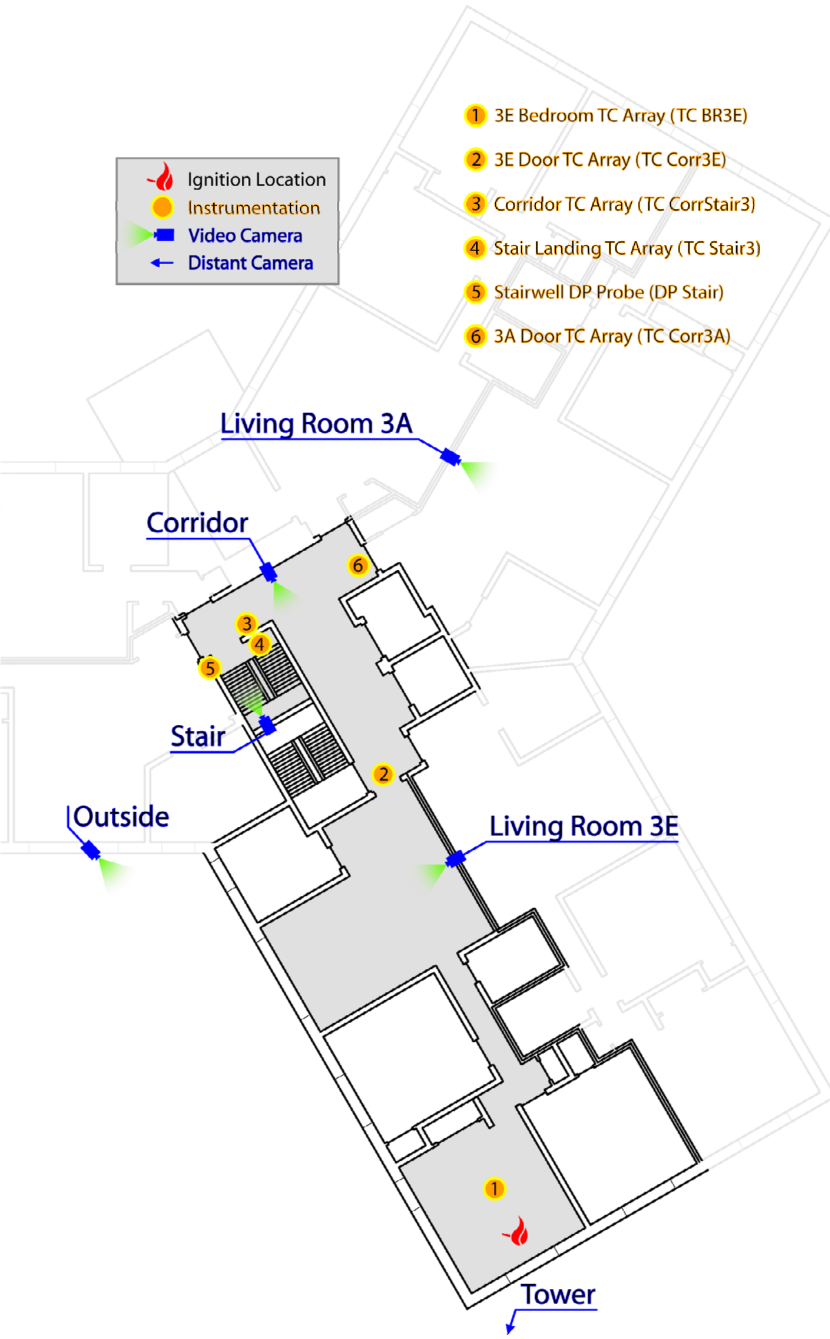



**Figure 3.12-2. Instrumentation and camera locations with labels.**

### 3.12.1 Observations

The observations are presented as a series of images captured from eight video camera locations. The camera positions inside the building are shown in Figure 3.12-2.

Figure 3.12-3 through Figure 3.12-19 present sets of eight images one from each camera position, at a given time, from the time of ignition to 36 min and 30 s (2190 s) after ignition. Images were captured every 4 min and at times when events had taken place that demonstrate the experimental objectives. Each image view is labeled. The first view (LIV RM A) at the top left of each figure shows the living room of apartment 3A; across the view are the windows. The top right view (LIV RM E) was of the living room in apartment 3E looking across to the windows. The corridor view (CORRIDOR) shows the corridor leading up to the open apartment doorway. Next to that, the outside lobby view (LOBBY) shows the area just outside the lobby doors. The view (STAIR) shows the stairwell with a camera from the floor below the fire looking up to the fire floor. Next to that is the outside view (OUTSIDE) which shows an alternate view of the outside of the apartment from a window in another wing of the building. The bottom left view (ROOF) shows the bulkhead door at the top of the stairwell and the bottom right view (TOWER) shows an external view of the fire apartment.

Figure 3.12-3 shows the images at the time of ignition. At this point, the eight video views were clear and unobstructed. As noted earlier, no thermal imagers were used for this experiment.

Figure 3.12-4 shows the images at 240 s (4 min) after ignition. At this point smoke from the fire in the bedroom had reduced the visibility in the living room of apartment 3E and the public corridor to nearly zero. Some smoke had leaked around the closed 3$^{rd}$ floor stair A door, and a small amount of smoke was visible at the ceiling level of the living room in apartment 3A.

Figure 3.12-5 shows the images at 480 s (8 min) after ignition. By this time the lobby doors, the 1$^{st}$ floor stair A door, the 3$^{rd}$ floor stair A door, and the bulkhead doors had been opened 206, 177, 156, and 97 s prior, respectively. A significant volume of smoke can be seen venting from the bulkhead door. The smoke layer had moved into the stairwell. The views of the living room in apartment 3E and the public corridor are still obscured. The smoke in living room 3A had increased, but a clear smoke layer was not yet visible in the living room 3A view.

Figure 3.12-6 shows the images at 600 s (10 min) after ignition. At this point three of the four panes of the bedroom double window were broken by the fire. Flames can be seen pushing out of the window, against the wind. The amount of smoke in the stairwell had increased and had descended below the fire floor level. Significant amounts of smoke were flowing out of the bulkhead doorway.

Figure 3.12-7 shows the images at 720 s (12 min) after ignition. The bedroom double window in the ignition bedroom had completely failed at 632 s. Smoke from the bulkhead door had flooded the roof area outside the door completely obscuring the view. The smoke layer had descended about halfway down stairway A between floor 2 and 3. The smoke in the living room of apartment 3A continued to reduce visibility in that view. Smoke can be seen leaking to the outside from the living room windows in apartment 3E.

Figure 3.12-8 shows the images at 930 s (15 min and 30 s) after ignition. These images show the conditions prior to the start of suppression. FBN 2 is being put into position. The window frame has been partially detached from the building.

Figure 3.12-9 shows the images at 960 s (16 min) after ignition. FBN 2 began flowing approximately 200 gpm in a solid stream into the ignition bedroom 17 s prior. The effects of FBN 2 are not yet visible in any of the 8 views however.

Figure 3.12-10 shows the images at 1200 s (20 min) after ignition. The water flow was stopped at 1017 s. The fire in the bedroom was reduced. The center pane of apartment 3E's living room window was vented manually at 1097 s. The smoke layer had descended the stairwell from floor 3 to floor 2. Flames were visible in the living room E view.

Figure 3.12-11 shows the images at 1360 s (22 min and 40 s) after ignition. The fire in the living room of apartment 3E continued to burn. The flames from the living room can be seen exiting the window. During the time period from 1301 s to 1348 s, the FBN 2 nozzle was flowing into the bedroom double window opening. The stream did not have a "straight shot" down the hallway. There was no visible suppression effect on the fire in the living room from the water that was discharged into the bedroom.

At 1362 s after ignition, an aearosol generating device was activated and lowered into the living room window opening from above. Within seconds, the deployment of a WCD was started in an attempt to keep the fire extinguishing agent in the living room. The agent suppressed the flames in the living room for approximately 50 seconds. At 1420 s, the furnishings in the living room appeared to be fully involved again. Figure 3.12-12 shows the images at 1440 s (24 min) after ignition. The WCD, which did not fully cover the window, can be seen in the outside view. Smoke flow out of the bulkhead door increased significantly.

Figure 3.12-13 shows the images at 1560 s (26 min) after ignition. The bulkhead door had just been closed. The WCD was removed approximately 45 s prior. Flames from the apartment 3E doorway can be seen in the center of the corridor view. Smokey conditions remained in apartment 3A.

Figure 3.12-14 shows the images at 1680 s (28 min) after ignition. Smoke had descended down the stairwell view, reducing visibility in that view. The fire in the living room continued to burn.

Figure 3.12-15 shows the images at 1710 s (28 min and 30 s) after ignition. All three of the 27 inch PPV fans were operating by this time. Two PPV fans were located outside in front of the lobby doors, and one PPV fan was located in front of the 1st floor doorway to stair A. As a result, the stair was cleared of smoke and additional smoke can be seen pushing around the edges of the closed bulkhead door.

Figure 3.12-16 shows the images at 1920 s (32 min) after ignition. Flames from the living room of apartment 3E were visible in the corridor view. The stair remained clear of smoke.

Figure 3.12-17 shows the images at 2155 s (35 min and 55 s) after ignition. These images were recorded at the time that FBN 2, began to flow water into the living room. The flow rate was approximately 210 gpm through a smooth bore tip.

Figure 3.12-18 shows the images at 2160 s (36 min) after ignition. FBN 2 continued to flow water into the window of living room E. Flames were no longer visible in the living room E view.

Figure 3.12-19 shows the images at 2190 s (36 min and 30 s) after ignition. These conditions are representative of the conditions at the conclusion of the experiment. The fires in the bed room and living room were extinguished with the FBNs. The stair was kept clear from smoke with the fans on the 1st floor. The smoke that had leaked into apartment A appeared to be at its worst at 16 minutes after ignition.  The smoke began to slowly dissipate after that however visible smoke remained in the living room of apartment A at the conclusion of the experiment.

Figure 3.12-3. Experiment 3E, ignition.

Figure 3.12-4. Experiment 3E, 240s after ignition.


**Figure 3.12-5. Experiment 3E, 480s after ignition.**


**Figure 3.12-6. Experiment 3E, 600s after ignition.**

**Figure 3.12-7. Experiment 3E, 720s after ignition.**

Figure 3.12-8. Experiment 3E, 930s after ignition.


**Figure 3.12-9. Experiment 3E, 960s after ignition.**


Figure 3.12-10. Experiment 3E, 1200s after ignition.

Figure 3.12-11. Experiment 3E, 1360s after ignition.

**Figure 3.12-12. Experiment 3E, 1440s after ignition.**

Figure 3.12-13. Experiment 3E, 1560s after ignition.

**Figure 3.12-14. Experiment 3E, 1680s after ignition.**


**Figure 3.12-15. Experiment 3E, 1710s after ignition.**


**Figure 3.12-16. Experiment 3E, 1920s after ignition.**


Figure 3.12-17. Experiment 3E, 2155s after ignition.


Figure 3.12-18. Experiment 3E, 2160s after ignition.

Figure 3.12-19. Experiment 3E, 2190s after ignition.

### 3.12.2 Temperatures

Figure 3.12-20 through Figure 3.12-22 provide temperature data for five measurement locations on the fire floor at two elevations and throughout the height of the stairwell. The locations of the measurement points can be seen in Figure 3.4-2. The events that occurred during the experiment are listed on the top of the figures with lines at the time of the event. A time history for each thermocouple at each measurement location is located in Appendix D – Detailed Graphs.

Figure 3.12-20 shows the temperatures versus time at 2.1 m (7 ft) above the floor at 5 measurement locations, the bedroom, just outside the fire apartment, 3E, in the corridor, just outside Apartment 3A in the corridor, just outside the A stairwell doorway, and just inside the A stairwell on the landing. The temperature in the bedroom peaked 500 ºC (932 ºF), approximately 200 s after ignition. The temperature in the bedroom began to decrease due to ventilation limitations. After opening the 3rd floor door to the stair, at 320 s, the temperature in the bedroom began to increase again. After opening the bulkhead door, the temperatures in the bedroom went up to approximately 600 ºC (1112 ºF) and stayed at that level until the bedroom double window on the upwind side began to fail. Initially the wind driven flow cooled the bedroom. Then as the one side of the bedroom double window self vented the fire in the bedroom, quickly transitioned to flashover. At 600 s, temperatures throughout the fire floor are in excess of 400 ºC (752 ºF). The use of the FBN dramatically decreased the temperature in the bedroom. For the remainder of the experiment, the temperatures in the bedroom remained at less than 100 ºC (212 ºF) until the end of the experiment.

Figure 3.12-21 shows the temperatures at 1.2 m (4 ft) which would be more representative to where firefighters would be operating or occupants would be evacuating. These temperatures at 1.2 m (4 ft) followed the same trends as described in Figure 3.12-20. Until the living room window was manually vented at approximately 1100 s. The temperatures at 1.2 m (4 ft above the floor) exceed the temperatures at 2.1 m (7 ft) above the floor in the areas outside of the apartment due to the horizontal wind driven hot gas flows. The temperatures on the fire floor remained elevated until the PPV fans were activated at which point the temperatures cooled to less than 100 ºC (212 ºF), with the exception of a few brief spikes.

Figure 3.12-22 shows the temperatures 1.2 m (4 ft) above the landing on floors 1, 2, and at the landing above the 7th floor with access to the roof. The sensors located at floors 4 and 6 were damaged in previous experiments. The temperature at the bulkhead level tracked with the fire development in the bedroom from the time that the 3rd floor stair door was opened through suppression. At approximately 1100 s through the end of the experiments, the stair temperatures were driven by the living room fire. After the initial suppression of the fire, temperatures in the bedroom were within the tenable range for fully protected firefighters.

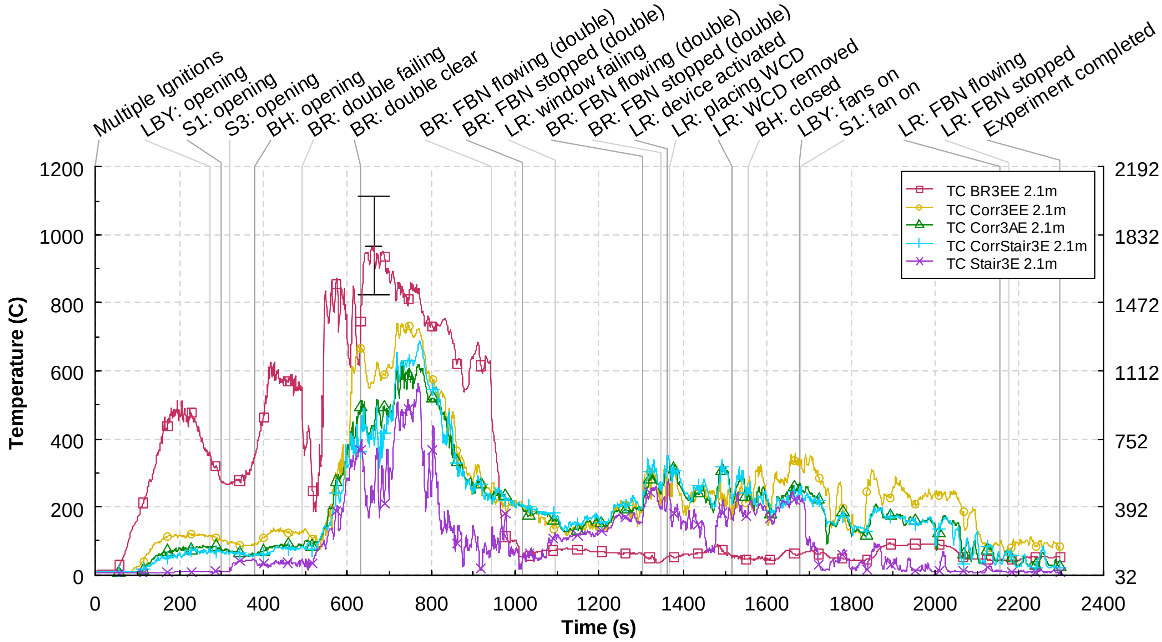



**Figure 3.12-20. 3E Temperature vs. time at 2.1 m above the floor**

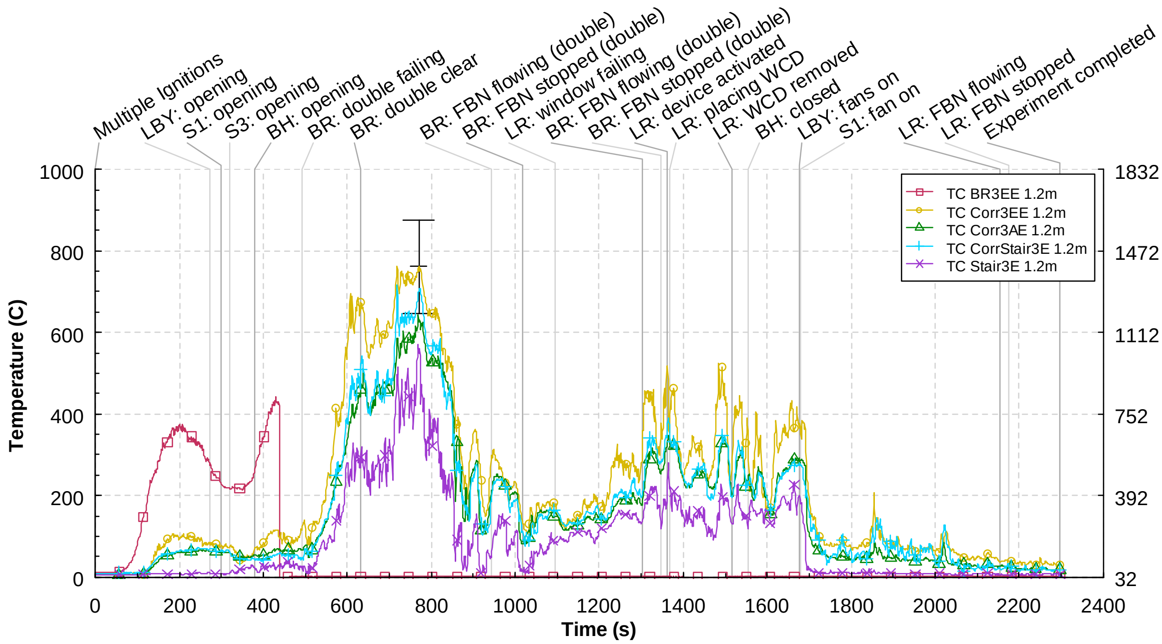



**Figure 3.12-21. 3E Temperature vs. time at 1.2 m above the floor**

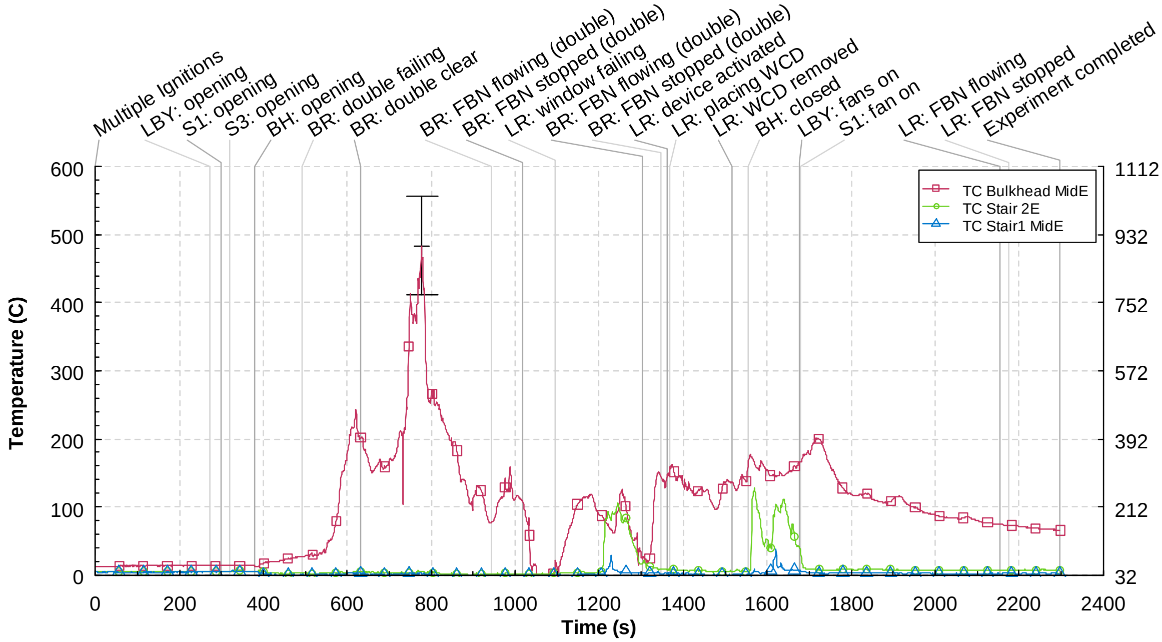



**Figure 3.12-22. 3E stairwell temperature vs. time**

### 3.12.3 Pressures

Average pressure measurements in the stairwell are shown in Figure 3.12-23. The differential pressure measurements were made at 1.2 m (4 ft) on the stairwell landing of every floor and referenced to an apartment on the same floor. With all of the doors to the stairwell closed the pressures remained below 5 Pa and only fluctuated slightly. During the period that the bulkhead door was open (380 s to 1550 s), the pressures decreased as the stairwell became part of the flow path exhausting combustion products out of the building. Once the bulkhead door was closed, the pressure increased in the stair. After the PPV fans were activated, pressures in the lower portion of the stairwell increased, while the pressures in the upper portion decreased due to cooling.

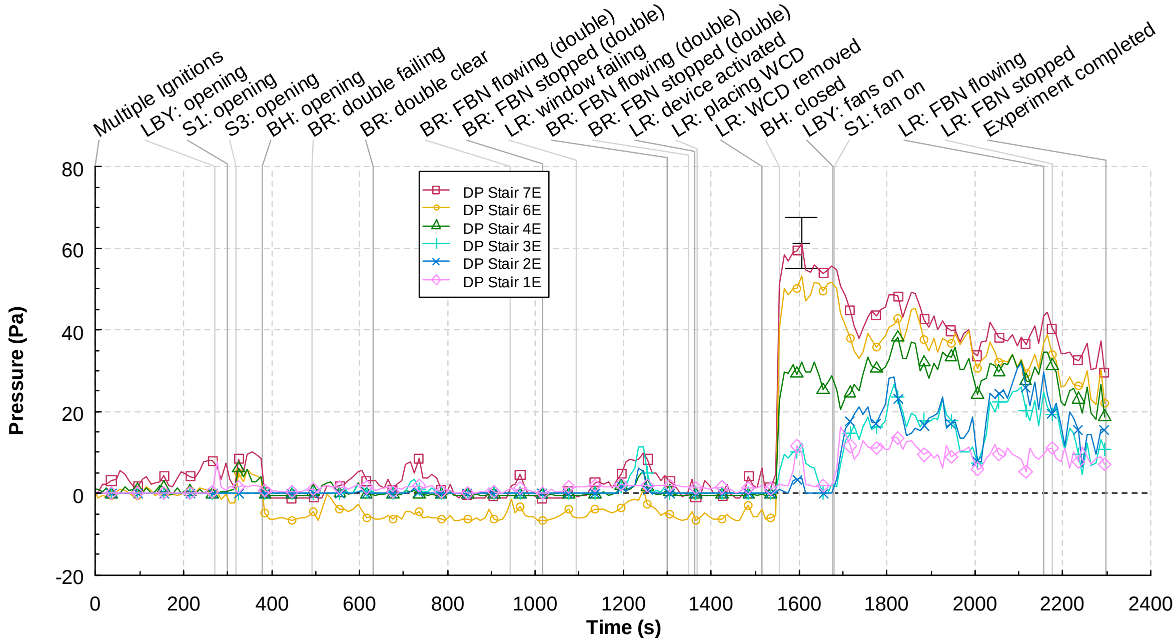



**Figure 3.12-23. 3E stairwell pressures vs. time**

### 3.12.4 Velocities

Average doorway velocities from 2 doorways; the doorway from the first floor to the stairwell, and the doorway at the bulkhead, were recorded versus time and shown in Figure 3.12-24. The three bi-direction probes in each door were averaged to provide the bulk flow through the doors. A time history for each probe at each measurement location is located in Appendix D – Detailed Graphs. Once the bulkhead door was opened the velocity (negative direction equates to flow out of the doorway) increased from zero to approximately 10 m/s (22 mph) as the bedroom flashed over and the bedroom double window opening was cleared. While the fire in the bedroom was being actively suppressed, the velocity of the flow out of the bulkhead went to zero. After suppression stopped and the living room window was manually vented the flow had an average velocity of approximately 8 m/s (18 mph) until the bulkhead door was closed. Hence the second application of water from the bedroom, the suppression device nor the partial WCD had an impact on the flow through the stairwell and the bulkhead doorway.

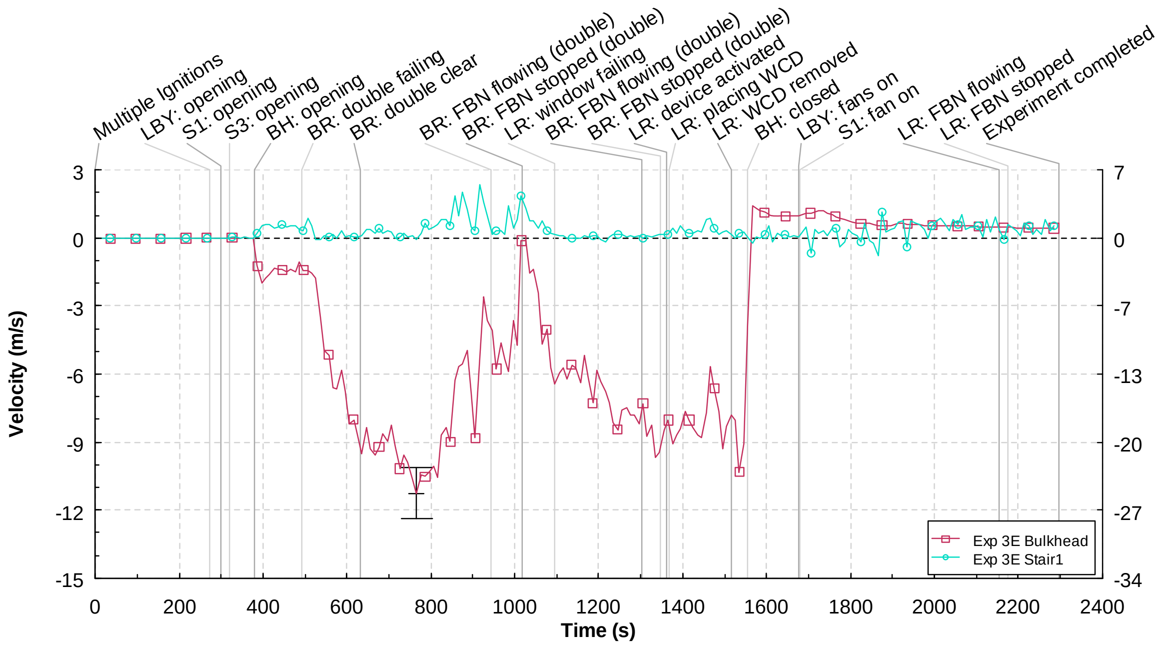



**Figure 3.12-24. 3E Velocities vs. time**

### 3.12.5 Discussion

The development of this fire was similar to previous fires. The fire grew until it became ventilation limited, the energy release and hence the temperature decreased until additional ventilation was provided via a window opening and/or ventilation from the stair. Hazardous thermal conditions for firefighters in full structural firefighting PPE are limited to the room of origin until a flow path through the structure is created. In this experiment, that flow path went from the open bedroom double window through apartment 3E, through the corridor and into the stairwell to the bulkhead doorway on the roof. As long as that flow path existed and there was a post flashover fire in the bedroom, hazardous thermal conditions existed on the fire floor for firefighters.

Suppressing the bedroom fire with the FBN 2 mitigated the thermal hazard within seconds. The second portion of the fire experiment began with the manual ventilation of the living room. While the fire in the living developed to the point where all of the fuels in the room were burning, it never created the level of thermal hazard that the bedroom fire did. The living room was rapidly extinguished with an externally applied water stream.

Positive pressure ventilation was used to clear and cool the stairwell in the latter stages of the fire. Again nothing that had not been demonstrated under more severe thermal conditions in previous experiments.

Based on the manufacturer's guide, the aerosol generator has been found to be effective in contained spaces [46]. In this experiment, the aerosol generator suppression device had a short term, approximately 50 s, impact on the fire in the living room. The WCD was deployed after the suppression device was placed via rope into the living room window in an effort to contain the extinguishing agent in the fire room. However, given the “wind driven” ventilation flowing through the living room and the limited coverage of the WCD, this was not an ideal application for this type of device.

## 3.13 Experiment 3A

The thirteenth experiment in the structure was located on the 3rd floor in apartment 3A. Experiment 3A was ignited in both the bedroom and the living room in an effort have both rooms involved in fire to examine the impact of a FBN deployed in the bedroom (Figure 3.11-1). This experiment also utilized a simulated wind provided by the MVU. The simulated wind was aimed into the bedroom window with a magnitude of approximately 9 m/s to 11 m/s (20 mph to 25 mph). The events that took place during the experiment to accomplish the experimental objectives below are shown in Table 3.13-1.

Experimental Objectives

- Create wind driven fire conditions from a bedroom fire
- Examine window failure times and conditions
- Examine building flows with different door opening configurations
- Control wind driven conditions with FBN
- Utilize portable PPV fans to control smoke movement

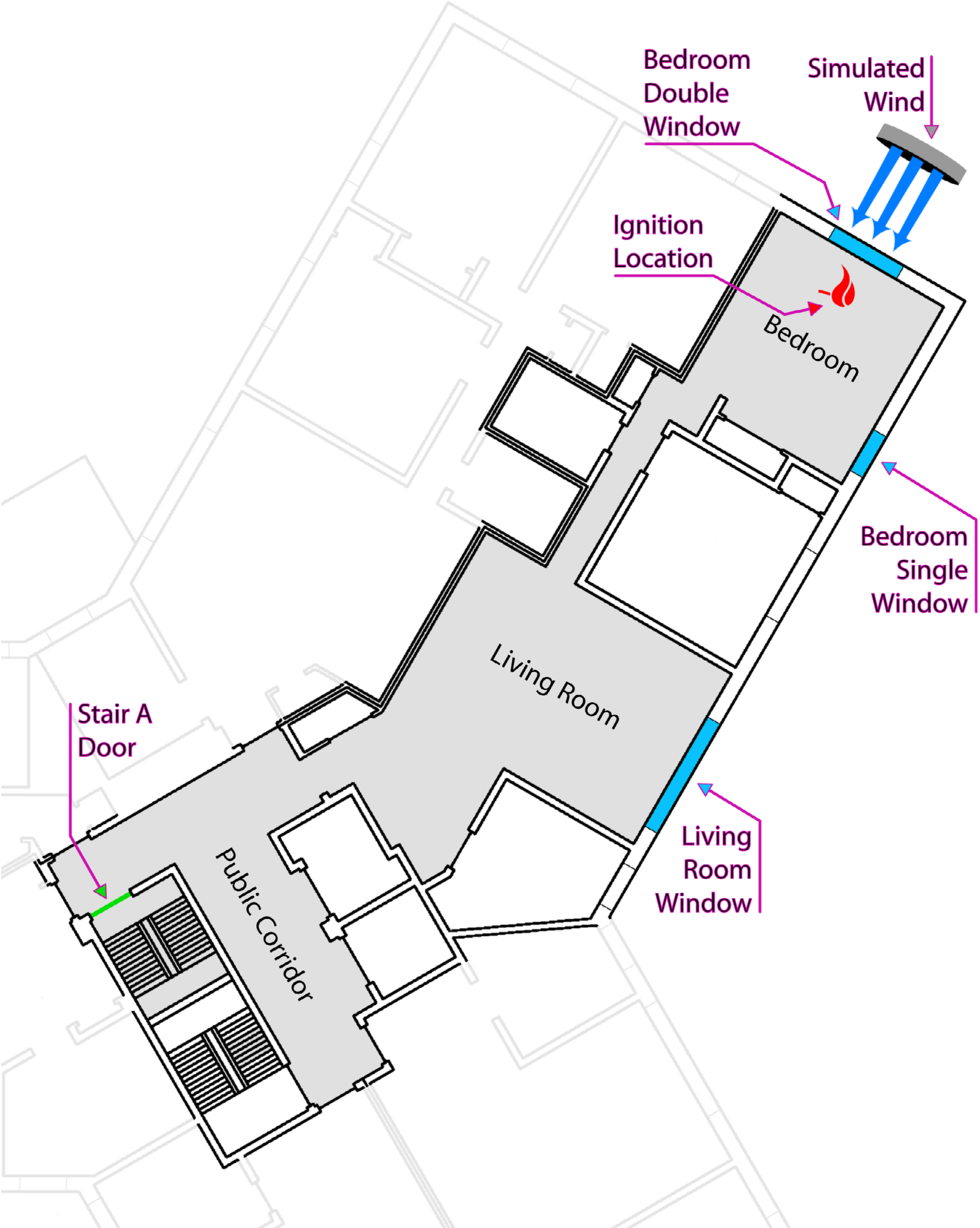



**Figure 3.13-1. 3rd floor apartment A floor plan with locations pertinent to Experiment 3A**

**Table 3.13-1: Experiment 3A Timeline**

| Start (s) | End (s) | Event Location | Event Description |
|---|---|---|---|
| 0 | 0 | Bedroom and living room | Ignition |
| 279 | 283 | Front lobby | Right door opened |
| 286 | 290 | 1st floor stair A | Door opened |
| 288 | 295 | 3rd floor stair A | Opened and closed |
| 329 | 331 | 3rd floor stair A | Opened |
| 381 | 383 | Bulkhead door | Opened |
| 496 | 497 | Bedroom double | Top left pane failed |
| 504 | 504 | Bedroom double | Top right pane failed |
| 559 | 561 | Bedroom double | Bottom right pane failed |
| 610 | 611 | Bedroom double | Bottom left pane failed |
| 695 | 695 | Bedroom double | FBN 1 started flowing (Smooth Bore) |
| 732 | 732 | Bedroom double | FBN 1 stopped |
| 772 | 773 | Living room window | Center pane failed |
| 838 | 838 | Living room window | Top left pane failed |
| 860 | 860 | Living room window | Top right pane failed |
| 877 | 877 | Living room window | Bottom left pane failed |
| 902 | 902 | Living room window | Bottom right pane failed |
| 922 | 922 | Living room window | FBN 1 started flowing (Smooth Bore) |
| 932 | 932 | Living room window | FBN 1 stopped |
| 954 | 954 | Living room window | FBN 1 started flowing (Smooth Bore) |
| 976 | 976 | Living room window | FBN 1 stopped |
| 1030 | 1044 | 1st floor stair A | 27 inch fan added |
| 1077 | 1079 | Bulkhead door | Closed |
| 1200 | 1200 | Experiment completed | |

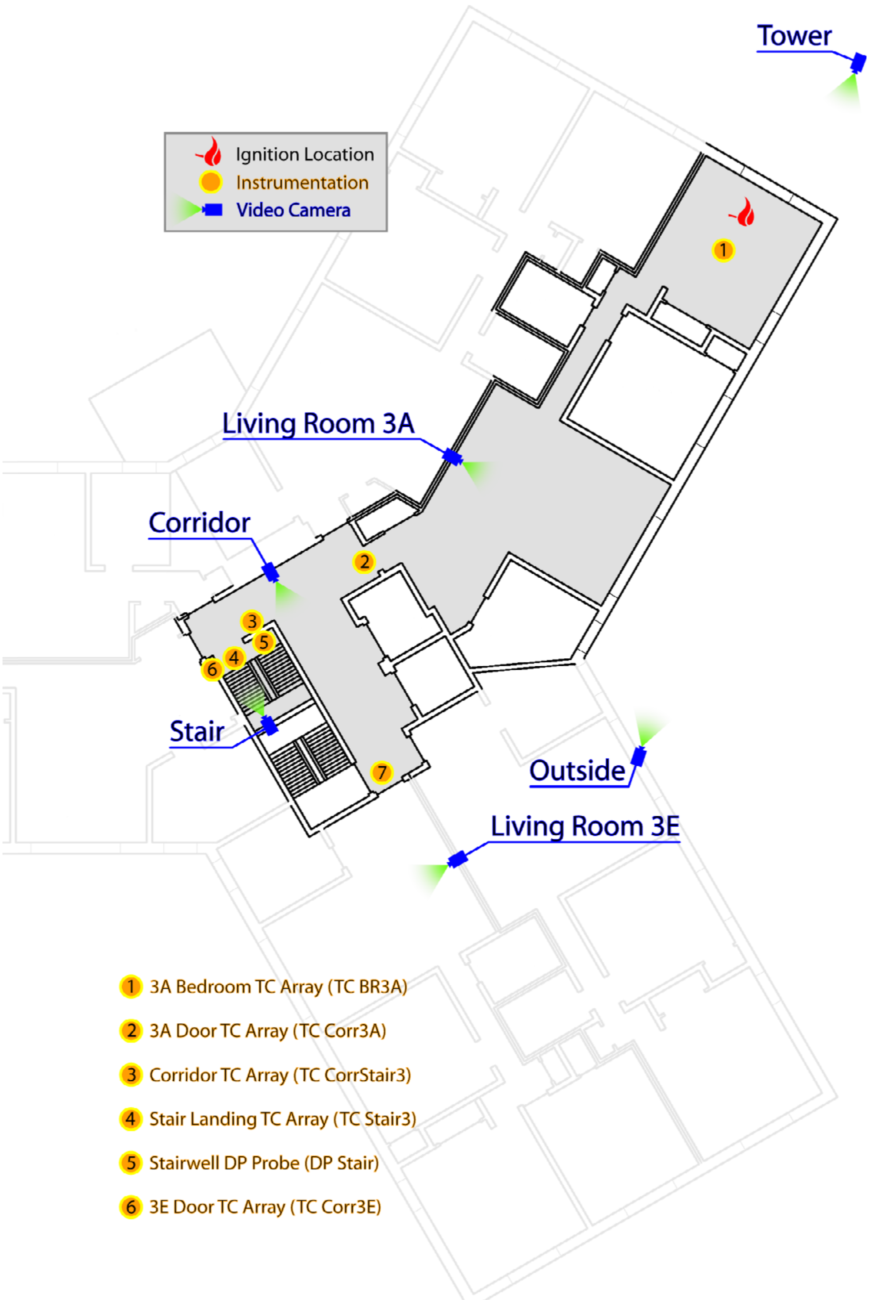



**Figure 3.13-2. Instrumentation and camera locations with labels.**

### 3.13.1 Observations

The observations are presented as a series of images captured from eight video camera locations. The camera positions inside the building are shown in Figure 3.13-2.

Figure 3.13-3 through Figure 3.13-15 present sets of eight images one from each camera position, at a given time, from the time of ignition to 20 min (1200 s) after ignition. Images were captured every

4 min and at times when events had taken place that demonstrate the experimental objectives. Each image view is labeled. The first view (LIV RM A) at the top left of each figure shows the living room of apartment 3A; across the view are the windows. The top right view (LIV RM E) was of the living room in apartment 3E looking across to the windows. The corridor view (CORRIDOR) shows the corridor leading up to the open apartment doorway. Next to that, the outside lobby view (LOBBY) shows the area just outside the lobby doors. The view (STAIR) shows the stairwell with a camera from the floor below the fire looking up to the fire floor. Next to that is the outside view (OUTSIDE) which shows an alternate view of the outside of the apartment from a window in another wing of the building. The bottom left view (ROOF) shows the bulkhead door at the top of the stairwell and the bottom right view (TOWER) shows an external view of the fire apartment.

Figure 3.13-3 shows the images at the time of ignition. At this point, the eight video views were clear and unobstructed. However, the view of the living room from the previous experiment was dark due to the fire damage it sustained from the previous experiment. The damage to the corridor from the previous experiment was also visible.

Figure 3.13-4 shows the images at 240 s (4 min) after ignition. Visibility in the corridor and the 3A living room was nearly zero at this point. No smoke was visible leaking past the closed 3$^{rd}$ floor stair A door. No smoke was visible from the outside of the structure at this time.

Figure 3.13-5 shows the images at 480 s (8 min) after ignition. By this time the lobby doors, the 1$^{st}$ floor stair A door, the 3$^{rd}$ floor stair A door, and the bulkhead doors had been opened 200s, 190s, 153s, and 98 s prior, respectively. Smoke was flowing up the stairwell through the open 3$^{rd}$ floor stair A door and out of the open bulkhead door. Visibility was returned slightly to the corridor view.

Figure 3.13-6 shows the images at 565 s (9 min and 25 s) after ignition. Three panes of the bedroom double window had failed and flames were being blown through the living room. Visibility in the stairwell and in the corridor was greatly reduced. Thick black smoke was still flowing out of the open bulkhead door.

Figure 3.13-7 shows the images at 625 s (10 min and 25 s) after ignition. The smoke and hot gases continued to flow through the apartment and into the corridor reducing visibility but there were no flames visible from the interior views. Flames were visible through the smoke in the stairwell view. There was an increase in the amount of smoke flowing out of the bulkhead doorway.

Figure 3.13-8 shows the images at 690 s (11 min and 30 s) after ignition. These were the conditions just prior to flowing the floor below nozzle. Flames were still visible at the bedroom window, visibility in the living room was zero and hot gases were flowing through the corridor into the stairwell. The stairwell view was lost due to increased heat on the landing below the fire floor. Smoke was leaking heavily from the living room windows and visibility on the roof was reduced from the smoke coming from the stairwell. Light smoke was visible coming from the lobby of the structure.

Figure 3.13-9 shows the images at 705 s (11 min and 45 s) after ignition. FBN 1 with a 1 ⅛ inch smooth bore nozzle had been flowing approximately 200 gpm for 10 s. The flames in the bedroom were reduced and the remaining views were very similar to the previous set.

Figure 3.13-10 shows the images at 720 s (12 min) after ignition. By this time the ignition bedroom double window had completely failed and FBN 1 had been started flowing water into it for 25 s. Smoke was leaking around the living room window. Visibility in all of the internal views is zero. Increased smoke and steam were coming from the bulkhead doorway.

Figure 3.13-11 shows the images at 840 s (14 min) after ignition. The FBN was stopped approximately 90 s prior and the living room window began to fail 67 s prior. Flames were visible coming from the failed living room window. Increased smoke was coming out of the lobby doorway and decreased smoke was visible coming from the bulkhead doorway.

Figure 3.13-12 shows the images at 910 s (15 min and 10 s) after ignition. Wind driven conditions were still present and the FBN was repositioned to the living room window. Flames were still visible in and from the living room window. There was no longer smoke coming from the lobby doorway.

Figure 3.13-13 shows the images at 935 s (15 min and 35 s) after ignition. The FBN was flowed into the living room for 10 s and the views show a large amount of steam coming from the structure and decreased visibility at the roof level. There were still no interior views at this time.

Figure 3.13-14 shows the images at 960 s (16 min) after ignition. FBN 1 was flowing water into the living room for the second time. A large volume of smoke and steam was pushing out of that window.

Figure 3.13-15 shows the images at 1200 s (20 min) after ignition. The experiment was completed by this time. The fire had largely burned down, but visibility had not returned to the internal views. Steam was visible flowing from the living room windows and there was no longer smoke coming from the bulkhead door. A PPV fan was added at the 1$^{st}$ floor stair door to pressurize and remove the smoke from the stairwell.


**Figure 3.13-3. Experiment 3A, ignition.**


**Figure 3.13-4. Experiment 3A, 240s after ignition.**

Figure 3.13-5. Experiment 3A, 480s after ignition.


**Figure 3.13-6. Experiment 3A, 565s after ignition.**

Figure 3.13-7. Experiment 3A, 625s after ignition.

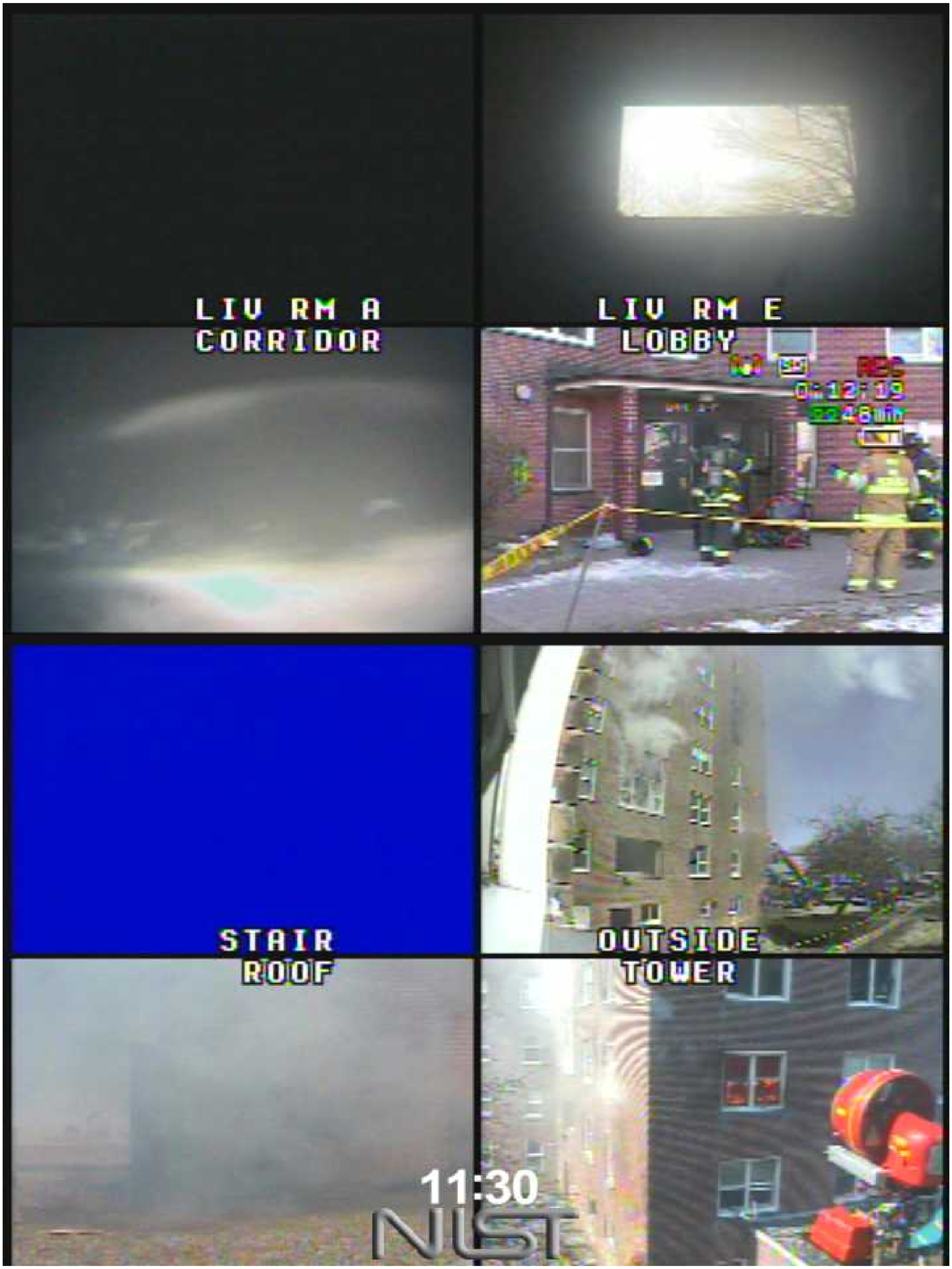


Figure 3.13-8. Experiment 3A, 690s after ignition.

**Figure 3.13-9. Experiment 3A, 705s after ignition.**

Figure 3.13-10.  Experiment 3A, 720s after ignition.


**Figure 3.13-11. Experiment 3A, 840s after ignition.**

**Figure 3.13-12. Experiment 3A, 910s after ignition.**

Figure 3.13-13. Experiment 3A, 935s after ignition.


**Figure 3.13-14. Experiment 3A, 960s after ignition.**

Figure 3.13-15. Experiment 3A, 1200s after ignition.

### 3.13.2 Temperatures

Figure 3.13-16 through Figure 3.13-18 provide temperature data for five measurement locations on the fire floor at two elevations and throughout the height of the stairwell. The locations of the measurement points can be seen in Figure 3.13-2. The events that occurred during the experiment are listed on the top of the figures with lines at the time of the event. A time history for each thermocouple at each measurement location is located in Appendix D – Detailed Graphs.

Figure 3.13-16 shows the temperatures versus time at 2.1 m (7 ft) above the floor at 5 measurement locations, the bedroom, just outside the fire apartment in the corridor, just outside Apartment 3E in the corridor, just outside the A stairwell doorway, and just inside the A stairwell on the landing. The temperature in the bedroom increased to above 300 ºC (572 ºF) before it became ventilation limited and the temperature decreased. Opening stairwell doors maintained the temperature but opening the bulkhead door allowed the bedroom to transition to flashover and fail the window subjected to the wind. Once the wind was able to enter the apartment the temperature decreased briefly as the cold air flowed in and then the temperature increased quickly to 800 ºC (1112 ºF) in the bedroom, over 500 ºC (932 ºF) in the corridor and over 300 ºC (572 ºF) in the stairwell. The temperatures all decreased quickly to approximately 200 ºC (392 ºF) or below after the FBN flowed for 37 s.

Figure 3.13-17 shows the temperatures at 1.2 m (4 ft) which would be more representative to where firefighters would be operating or occupants would be evacuating. These temperatures were almost identical to the 2.1 m (7 ft) measurements because the wind was flowing into the apartment for the duration of the experiment. The wind was mixing all the gases and there was no layering in the corridor or stairwell.

Figure 3.13-18 shows the temperatures 1.2 m (4 ft) above the landing on floors 1, 2, and at the landing above the 7$^{th}$ floor with access to the roof. The temperatures in the stairwell remained near ambient until the bedroom window failed. Prior to suppression the temperature above the fire floor, near the bulkhead door was above 400 ºC (752 ºF). The temperature on the 2$^{nd}$ floor landing, below the fire floor had reached 350 ºC (662 ºF) and the 1$^{st}$ floor increased to above 100 ºC (212 ºF). The temperatures recovered slightly as the fire in the living room increased but the temperatures remained below 200 ºC (392 ºF). The stairwell temperatures returned to ambient once the FBN flowed into the living room and the PPV fan was activated.

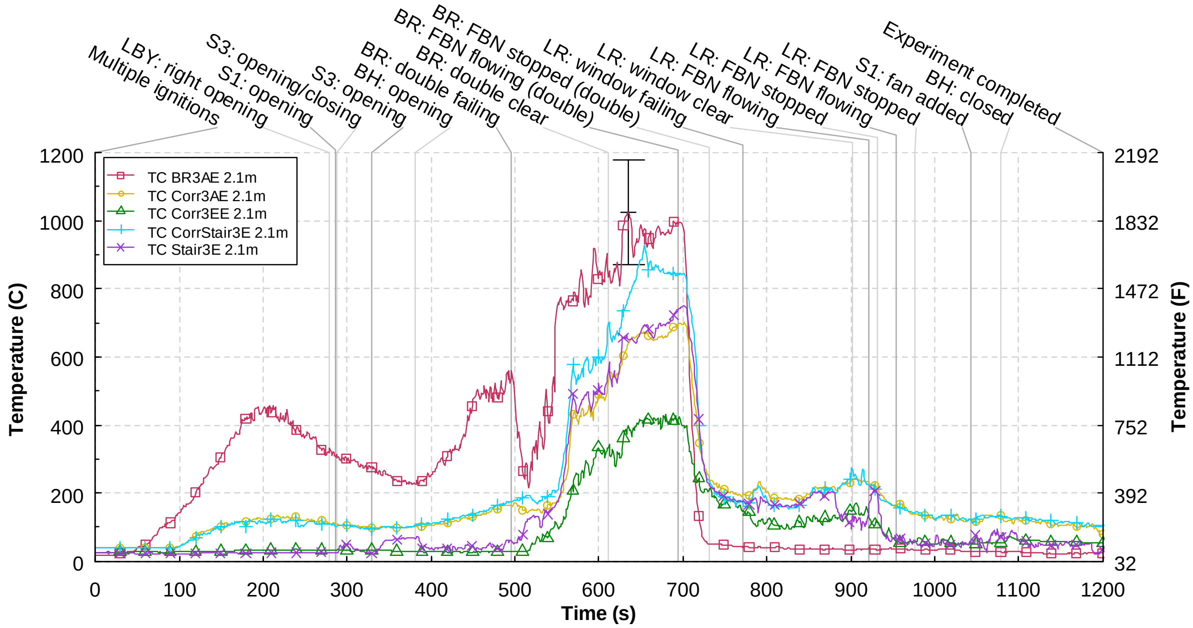



Figure 3.13-16. 3A Temperature vs. time at 2.1 m above the floor

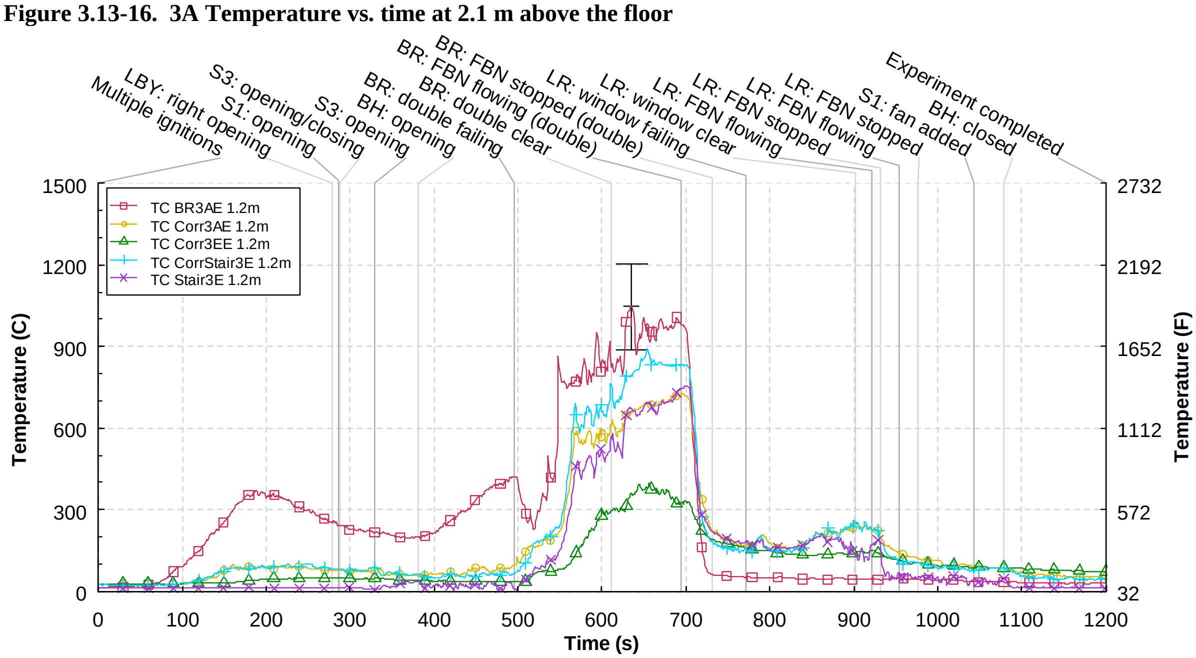



Figure 3.13-17. 3A Temperature vs. time at 1.2 m above the floor

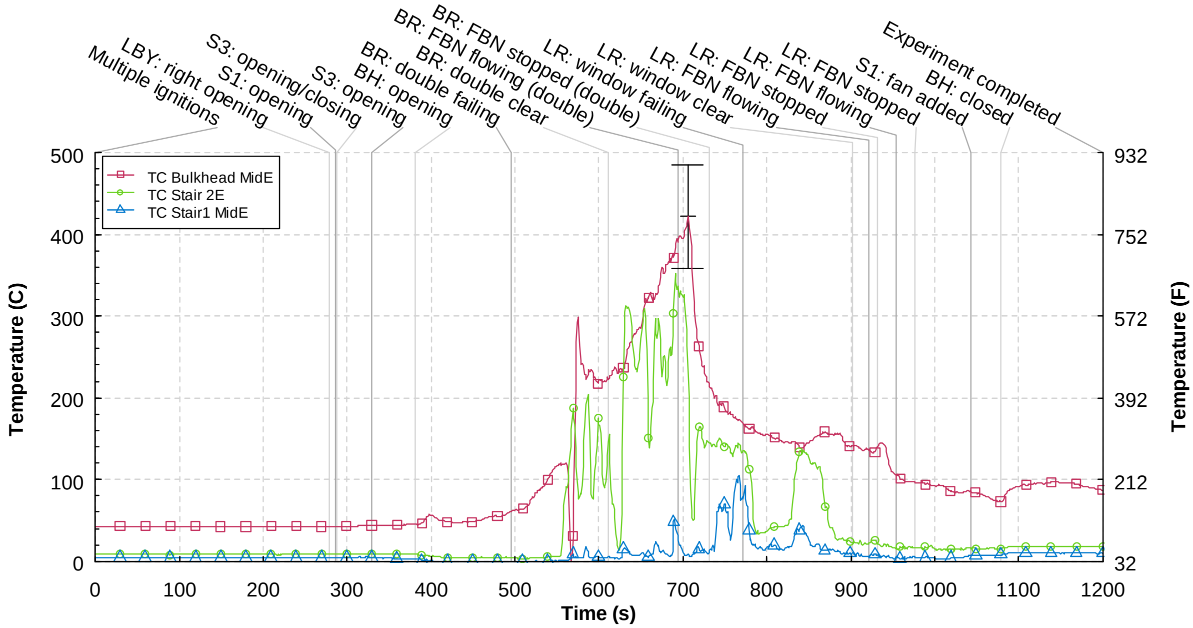



**Figure 3.13-18. 3A stairwell temperature vs. time**

### 3.13.3 Pressures

Average pressure measurements in the stairwell are shown in Figure 3.13-19. The differential pressure measurements were made at 1.2 m (4 ft) on the stairwell landing of every floor and referenced to an apartment on the same floor. With all of the doors to the stairwell closed the pressures remained below 5 Pa and only fluctuated slightly. The pressure slightly increased up to 10 Pa above the fire floor after the fire floor door was opened. Once the bulkhead door was opened this pressure dropped below zero as the stairwell became the flow path. When the wind driven fire was at its peak the pressures in the area of the fire floor reached as high as 20 Pa. As the fire was suppressed by the FBN the pressure also dropped to below 10 Pa. Adding the fan at the end of the experiment increased the stairwell pressures to an average of 20 Pa with the bulkhead door closed.

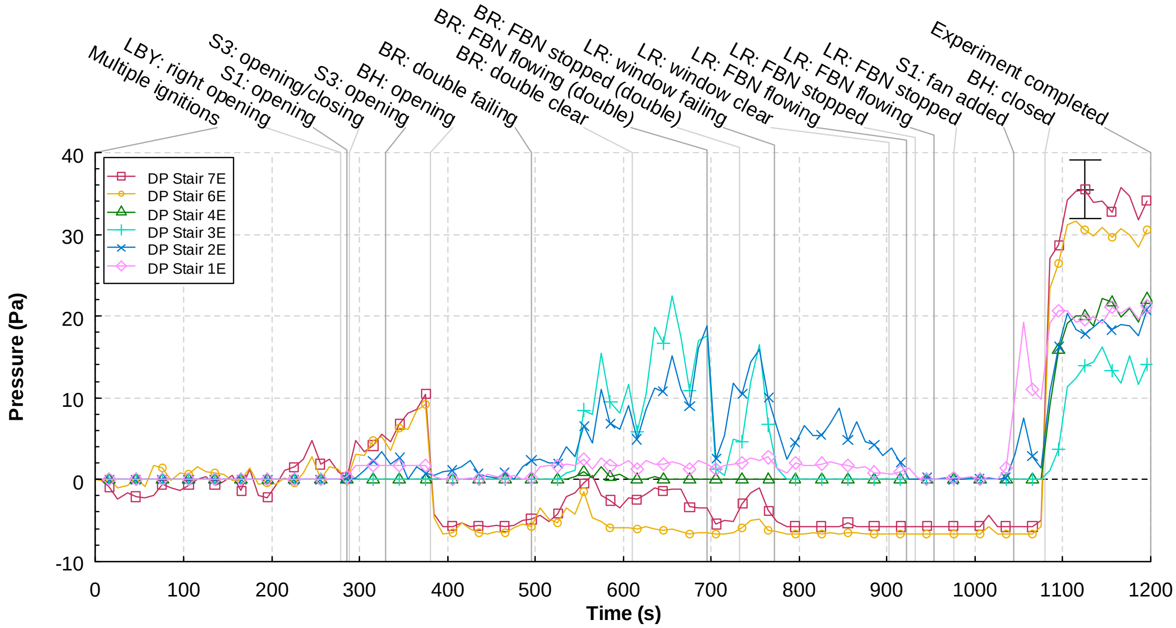



**Figure 3.13-19. 3A stairwell pressures vs. time**

### 3.13.4 Velocities

Average doorway velocities from 2 doors; the door at the base of the stair and the door at the bulkhead, were recorded versus time and shown in Figure 3.13-20. The three bi-direction probes in each door were averaged to provide the bulk flow through the doors. A time history for each probe at each measurement location is located in Appendix D – Detailed Graphs.

The average flow through the 1st floor stair door was less than 2 m/s (4 mph). The bulk flow out of the bulkhead door peaked around 14 m/s (31 mph) and decreased after suppression to around 5 m/s (11 mph) and ultimately decreased to 0 m/s after the activation of the fan and the closing of the bulkhead door.

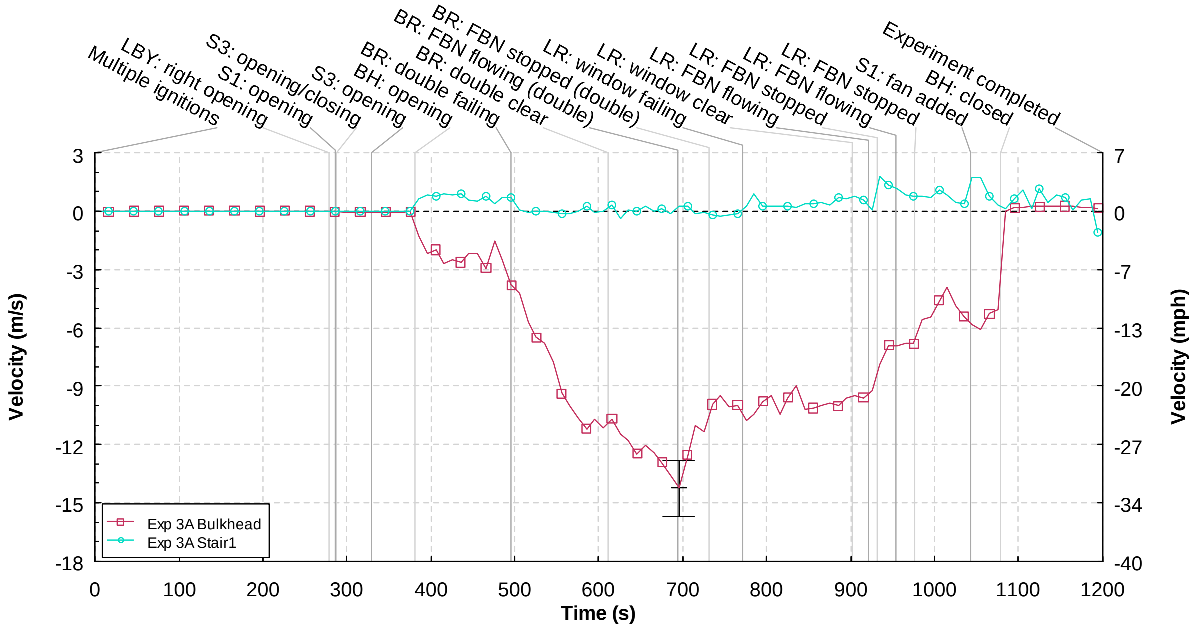



**Figure 3.13-20. 3A Velocities vs. time**

### 3.13.5 Discussion

Experiment 3A examined the impact of a smooth bore FBN 1 on a wind driven, multi-room apartment fire. The fire in the bedroom achieved post-flashover (temperatures floor to ceiling in excess of 600 ºC (1100 ºF), shortly after the windows began to self vent at 497 s. The peak temperatures were generated by the creation of a flow path between the bedroom and the vented stairwell. The failure (self venting) of half of the bedroom double window combined with the open door between the fire floor and the stairwell and the open bulkhead door at the top of the stair led to the creation of a flow path. Temperatures in the flow path between the open bedroom window and the 5th floor stair exceeded 400 ºC (752 ºF) throughout the fire floor at both the 2.1 m (7 ft) and 1.2 m (4 ft) elevations above floor level. Heat and smoke entered the stair, resulting in poor visibility and increased temperatures both above and below the fire floor. In addition, the ventilation condition caused by the venting and doors resulted in a peak gas velocity of approximately 14 m/s (31 mph) out of the bulkhead doorway. The thermal conditions created during this experiment were not conducive to a direct frontal fire attack and firefighters remote from the fire in the stairwell would have been threatened if they were in the flow path due to extreme temperatures.

The first pane of the bedroom window failed at 497 s and the window completely failed at 611 s. The temperature in the center of the bedroom at 1.2 m (4 ft) at the time of window failure was approximately 400 ºC (752 ºF). The temperature in the center of the room at the time of complete window failure was in excess of 900 ºC (1652 ºF). The partial failure of the window and the ventilation from the open stair door on the fire floor provided the oxygen required to achieve flashover. The majority of the window did not fail until after the room transitioned to flashover.

The FBN caused an immediate reduction of temperature on the fire floor and in the stairwell. The FBN extinguished the fire in the bedroom, but not the fire in the living room. However, the wind driven conditions were minimized by the application of water into the bedroom reducing temperatures to the point where firefighters could enter the corridor and advance on the fire. The fire in the living room was allowed to re-develop. The FBN was repositioned to make an attack on the living room and extinguished the fire.

The addition of the PPV fan at the base of the stair in conjunction with closing the bulkhead door to increase the stairwell pressure kept the smoke out of the stairwell from the knocked down fire. This would allow crews to overhaul in a more tenable atmosphere.

## 3.14 Experiment 3G/K

The fourteenth and last experiment in the structure involved two apartments on the 3rd floor, apartments 3G and 3K. Apartment 3G was on the up wind side of the building and was used as the ignition apartment. The fire was ignited in three locations simultaneously; both of the bedrooms and the living room as shown in Figure 3.14-1. In this experiment, the natural wind played a significant role. The wind was coming from the WNW and hitting the side of the building at an average wind speed in the range of 7 m/s to 9 m/s (15 mph to 20 mph), with gusts of up to 13 m/s (29 mph), as shown in Appendix C – Wind Measurements and Descriptions. Later in this experiment a simulated wind provided by the MVU was also utilized. The simulated wind was aimed into the bedroom window with a magnitude of approximately 9 m/s to 11 m/s (20 mph to 25 mph). Apartment K was located on the down wind side of the apartment and was loaded with fuel. The flow path on the 3rd floor was arranged to go from the most remote bedroom in apartment G through the open apartment door into the public corridor into the open door of apartment K to the open bedroom windows on the downwind side of the building. The events that took place during the experiment to accomplish the experimental objectives below are shown in Table 3.14-1.

Experimental Objectives

- Create wind driven fire conditions from an apartment fire
- Examine window failure times and conditions
- Examine building flows with different door opening configurations
- Allow wind driven fire to vent through another apartment down wind (horizontal flow path)
- Utilize portable PPV fans to control smoke movement
- Allow WCD to be subjected to fire conditions for a long period of time
- Control wind driven conditions with FBN

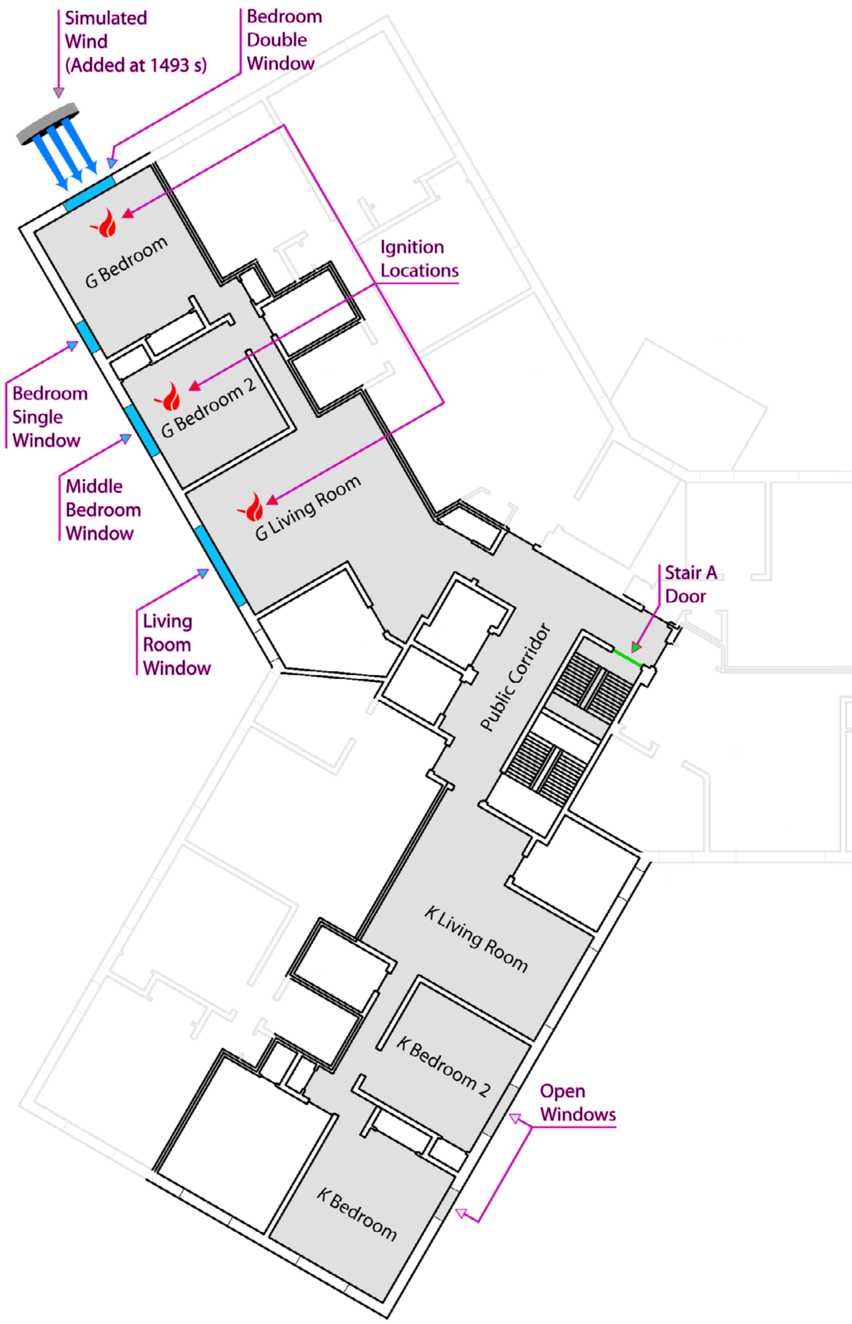



**Figure 3.14-1. 3rd floor apartment G and K floor plans with locations pertinent to Experiment 3G/K**

**Table 3.14-1: Experiment 3G/K Timeline**

| Start (s) | End (s) | Event Location | Event Description |
|---|---|---|---|
| 0 | 0 | All 3 rooms in G | Ignition |
| 247 | 250 | Front lobby | Left door opened |
| 262 | 267 | 1st floor stair A | Door opened |
| 303 | 303 | Bedroom single | Bottom pane failed |
| 352 | 413 | Bedroom single | Top pane failed |
| 423 | 427 | 3rd floor stair A | Door opened |
| 452 | 455 | Bulkhead door | Opened |
| 516 | 521 | Bulkhead door | Closed |
| 713 | 716 | Bulkhead door | Opened |
| 743 | 772 | Front lobby | 2 - 27 inch fans activated |
| 770 | 785 | 1st floor stair A | 27 inch fan activated |
| 831 | 834 | Bulkhead door | Closed |
| 1035 | 1045 | Living room window | Vented manually |
| | 1106 | Bedroom double | Top right pane failed |
| 1141 | 1142 | Bedroom single | WCD deployed |
| 1167 | 1167 | Bedroom double | Pane failed |
| 1168 | 1168 | Bedroom double | Pane failed |
| 1193 | 1194 | Bedroom double | Bottom right pane failed |
| 1257 | 1263 | Living room window | WCD deployed |
| 1467 | 1495 | Bedroom double | Air flow introduced |
| 1660 | 1661 | Middle bedroom double | WCD deployed |
| 1820 | 1831 | Bedroom double | Air flow removed |
| 2078 | 2082 | Bedroom double | FBN 1 started flowing (Smooth Bore) |
| 2220 | 2220 | Bedroom double | FBN 1 stopped |
| 2644 | 2657 | Living room window | WCD peeled away for stream |
| 2677 | 2683 | Living room window | FBN 1 started flowing (Smooth Bore) |
| 2765 | 2765 | Living room window | FBN 1 stopped |
| 3006 | 3006 | Experiment completed | |

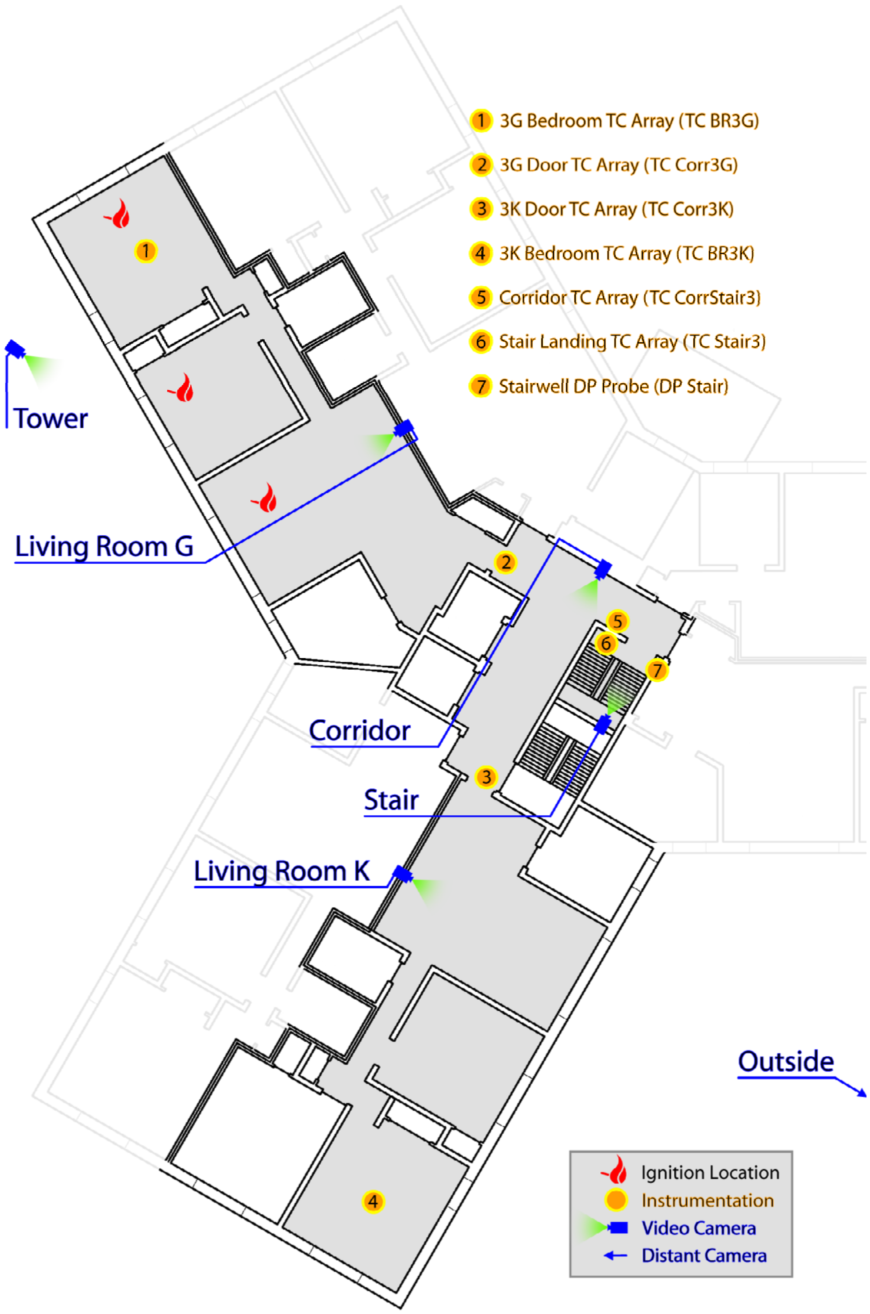



**Figure 3.14-2. Instrumentation and camera locations with labels.**

### 3.14.1 Observations

The observations are presented as a series of images captured from eight video camera locations. The camera positions inside the building are shown in Figure 3.14-2.

Figure 3.14-3 through Figure 3.14-28 present sets of eight images one from each camera position, at a given time, from the time of ignition to 48 min (2880 s) after ignition. Images were captured every

4 min and at times when events had taken place that demonstrate the experimental objectives. Each image view is labeled. The first view (LIV RM G) at the top left of each figure shows the living room of apartment 3G; across the view are the windows. The top right view (CORRIDOR) shows the corridor leading up to the open apartment doorway. The view (STAIR) shows the stairwell with a camera from the floor below the fire looking up to the fire floor. Next to that is the view (TOWER) which shows an exterior view of apartment 3G. The view (LIV RM K) shows the living room of apartment 3K with the windows strait across the view. Next to that, the view (ROOF) shows the bulkhead door at the top of the stairwell. The bottom, left view (LOBBY) shows the area just outside the lobby doors. The bottom, right view (not labeled) shows the 3K apartment (downwind side) from ground level outside the building.

Figure 3.14-3 shows the images at the time of ignition. At this point, the eight video views were clear and unobstructed. The corridor view appears dark due to the limited available light.

Figure 3.14-4 shows the images at 240 s (4 min) after ignition. At this point the smoke layer in apartment 3G had descended to the floor throughout. The smoke layer in the 3K apartment had descended to about 1.2 m (4 ft) above the floor in the living room. No smoke is leaking into the stairwell.

Figure 3.14-5 shows the images at 420 s (7 min) after ignition. Visibility was reduced to nearly zero in both living room views. A few seconds earlier, the bedroom single window (located on the upwind side of the building) finished self venting as shown in the tower view. Smoke is venting out of the open windows in the apartment 3K bedroom windows.

Figure 3.14-6 shows the images at 480 s (8 min) after ignition. Smoke continued to vent from the open 3K bedroom windows. The door from the fire floor to the stair was opened at 427 s (7.1 min). This allowed smoke to be pushed down the 3$^{rd}$ floor A stairwell and vent out of the open lobby doors. The bulkhead door was opened at 455 s (7.6 min) and closed again at 521 s (8.7 min). Very little smoke flowed up and out of the open bulkhead doorway.

Figure 3.14-7 shows the images at 580 s (9 min and 40 s) after ignition. Flames can be seen moving through the living room of apartment 3G and the thick looking smoke is rolling through the corridor. Smoke continued to vent through both the open bedroom windows in apartment 3 K and from the open front lobby doors. Just a few seconds before these images were recorded, the fire in the most remote bedroom in apartment 3G became underventilated to the point where flames were no longer visible. Flames were not readily seen from the tower video. This changed was followed by large puffs of black smoke being pushed out of the open bedroom single window against the prevailing wind.

Figure 3.14-8 shows the images at 600 s (10 min) after ignition. The puffs of smoke that had pushed out of the upwind bedroom window of apartment 3G, quickly transformed into "balls of fire" being pushed out of the upwind window. This phenomenon continued at a steady rate until the bulkhead door was opened at 716 s (11.9 min) after ignition.

Figure 3.14-9 shows the images at 720 s (12 min) after ignition. The bulkhead door had been opened 4 s prior, but no smoke was pushing from it. Visibility was still obscured in all the internal views. Large volumes of smoke were flowing out of the open bedroom windows in apartment 3K and out of the open lobby doors. A small amount of smoke was still being pushed out of the open window in apartment 3G.

Figure 3.14-10 shows the images at 780 s (13 min) after ignition. Approximately 10 s before these images were recorded, the two 27 inch PPV in front of the lobby doors were started. This reduced the amount of smoke coming out of the lobby doorway. Efforts were being made to start the PPV fan that was located in front of the doorway to stair A, at this time.

Figure 3.14-11 shows the images at 960 s (16 min) after ignition. The bulkhead door had been closed 126 s prior and the 27 inch fan at the 1st floor stair A door had been operating for approximately 3 minutes. Visibility had improved slightly in the stairwell view as the smoke density decreased. No smoke was venting through the lobby doors at this point. The smoke venting out of the open downwind bedroom windows in apartment 3K appeared to have gotten lighter in color and had increased in volume.

Figure 3.14-12 shows the images at 1120 s (18 min and 40 s) after ignition. A few seconds earlier the bedroom double window in apartment 3G failed, resulting in significant flame extension out of the double window as shown in the tower view. This reduced the amount of smoke that was being vented on the downwind side through apartment 3K.

Figure 3.14-13 shows the images at 1200 s (20 min) after ignition. In an effort to maintain flow into the public corridor and apartment 3K, a WCD had been placed over the bedroom single window in the 3G apartment bedroom furthest from the apartment exit 57 s prior. The flames pushing from that bedroom's double window intensified significantly in part because of the smoke being driven from the living room into the bedroom.

Figure 3.14-14 shows the images at 1440 s (24 min) after ignition. A WCD had been placed over the living room window 164 s prior. This closed off both of the upwind openings in apartment 3G. The amount of flame extension from the bedroom double window was reduced and fire was visible in the apartment 3G living room. However no smoke was flowing out of the down wind apartment.

Figure 3.14-15 shows the images at 1520 s (25 min and 20 s) after ignition. At this time the MVU had been moved into position and was being adjusted to blow the heat back through apartment 3G. This would challenge the WCDs that had been deployed and potentially generate heat behind them.

Figure 3.14-16 shows the images at 1680 s (28 min) after ignition. A WCD had been placed over the second bedroom double window 19 s prior in an effort to maintain a closed vent in that room. The stair was kept clear. A small amount of smoke was venting from the open bedroom windows in apartment 3K.

Figure 3.14-17 shows the images at 1775 s (29 min and 35 s) after ignition. A significant change in the conditions in the living room in apartment 3G began 5 s prior. Large volume of billowing black smoke pushed around the WCD. Flames from the living room window followed. The smoke vented on the downwind side of the building through apartment 3K became darker in color and increased in volume.

Figure 3.14-18 shows the images at 1820 s (30 min and 20 s) after ignition. Flames coming up from behind the WCD over the living room window were being driven by the wind into the 4$^{th}$ floor, where safety crews were positioned. The amount of smoke venting from apartment 3K had increased significantly and had gotten very dark in color. Given the concern that the conditions on 4$^{th}$ floor were decaying, the simulated wind was removed from the bedroom double window in apartment 3G.

Figure 3.14-19 shows the images at 1920 s (32 min) after ignition. The MVU was removed approximately 90 s prior. The flow quickly reversed, with flames extending out of the bedroom double window for a brief period. Flame extension from behind the living room WCD stopped and the smoke that was venting from the 3K bedroom windows stopped as well.

Figure 3.14-20 shows the images at 2070 s (34 min and 30 s) after ignition. These images were captured to show the conditions just before suppression was started with a FBN.

Figure 3.14-21 shows the images at 2100 s (35 min) after ignition. Suppression with FBN 1 began at 2082 s after ignition. The 1-1/8$^{th}$ inch, smooth bore nozzle tip was used, flowing approximately 200 gpm. Water flow continued until 2200 s. Copious amounts of white vapor flowed out of the bedroom double window opening. A very small amount of smoke was venting from the open bedroom windows in apartment 3K. The stair was kept clear by the PPV fans.

Figure 3.14-22 shows the images at 2160 s (36 min) after ignition. Suppression continued with no visible changes from the previous images.

Figure 3.14-23 shows the images at 2260 s (37 min and 40 s) after ignition. Suppression stopped at 2220 s. Flames were present in the living room in apartment 3G. The glow could be seen in both the living room view and through the WCD in the tower view. Smoke began to vent from apartment 3K again.

Figure 3.14-24 shows the images at 2400 s (40 min) after ignition. No ventilation or suppression conditions were changed between 2220 s and 2400 s. The flames in the living room were no longer visible in the living room view. Smoke continued to vent from behind the WCD over the living room window opening in apartment 3G and the from the open bedroom windows in apartment 3K.

Figure 3.14-25 shows the images at 2640 s (44 min) after ignition. A portion of the WCD over the living room opening was being moved to in order to use a FBN to flow water directly into the living room. As air was allowed into the living room, the flames could be seen again.

Figure 3.14-26 shows the images at 2685 s (44 min and 45 s) after ignition. A few seconds before these images were recorded, FBN 1, with the same smooth bore nozzle used earlier in the experiment began to flow approximately 200 gpm of water into the living room. The flames in the living room were quickly extinguished.

Figure 3.14-27 shows the images at 2715 s (45 min and 15 s) after ignition. FBN 1 was still applying water into the living room. Significant volumes of white vapor poured out of the bedroom double window. White vapor could also be seen venting out of apartment 3K.

Figure 3.14-28 shows the images at 2880 s (48 min) after ignition. FBN 1 flowed in to the living room for approximately 90 s. These images were recorded after the suppression effort was completed. Vapor was still coming out of the upwind bedroom. A very modest amount of smoke was still being vented from the open windows in the downwind apartment. The PPV fans continued to keep the stairwell free from smoke.

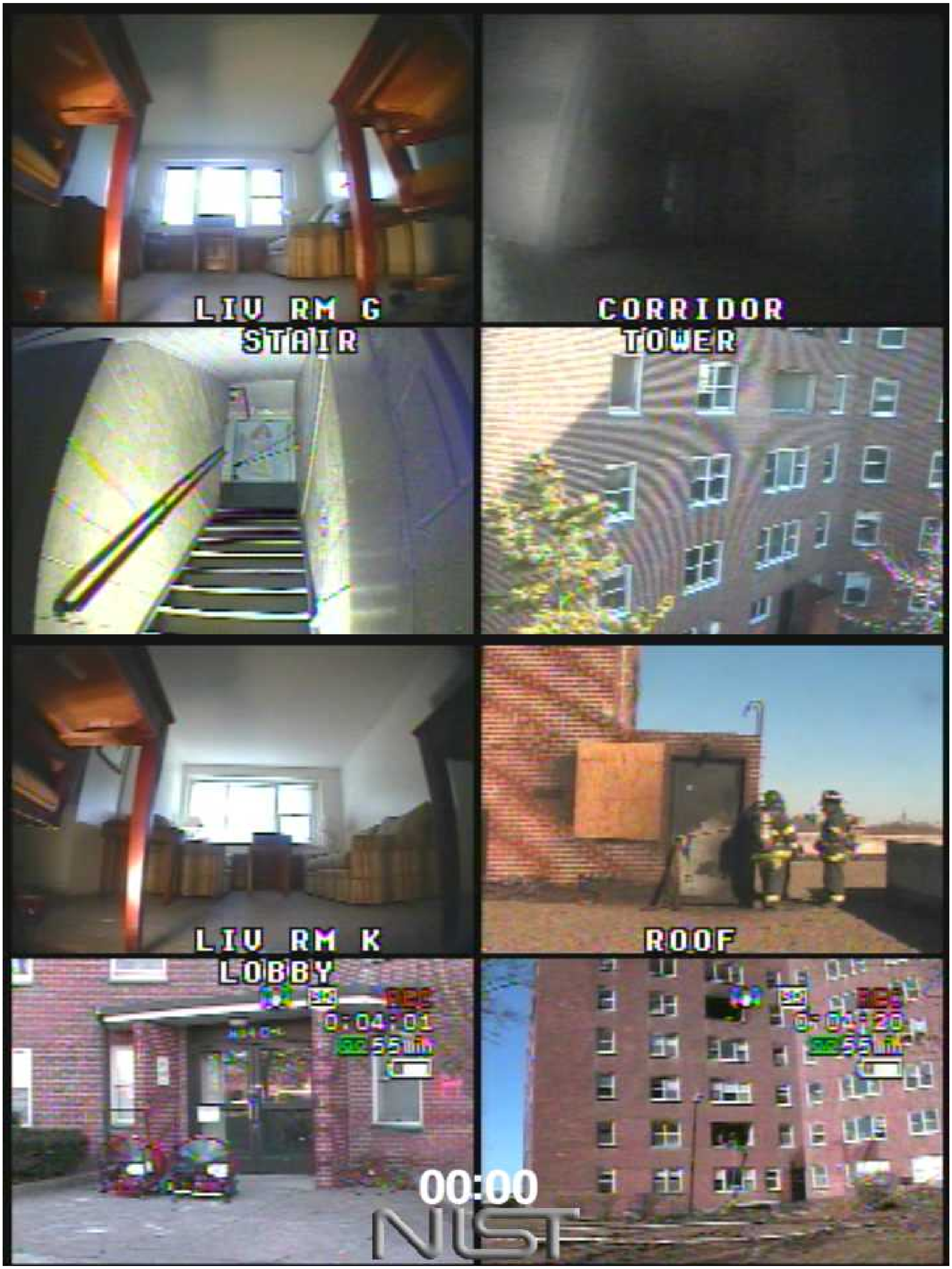


Figure 3.14-3. Experiment 3G/K, ignition.

Figure 3.14-4. Experiment 3G/K, 240s after ignition.

Figure 3.14-5. Experiment 3G/K, 420s after ignition.


**Figure 3.14-6. Experiment 3G/K, 480s after ignition.**


**Figure 3.14-7. Experiment 3G/K, 580s after ignition.**

Figure 3.14-8.  Experiment 3G/K, 600s after ignition.

Figure 3.14-9. Experiment 3G/K, 720s after ignition.


Figure 3.14-10. Experiment 3G/K, 780s after ignition.


Figure 3.14-11. Experiment 3G/K, 960s after ignition.

Figure 3.14-12. Experiment 3G/K, 1120s after ignition.


**Figure 3.14-13. Experiment 3G/K, 1200s after ignition.**

Figure 3.14-14. Experiment 3G/K, 1440s after ignition.


**Figure 3.14-15. Experiment 3G/K, 1520s after ignition.**


Figure 3.14-16. Experiment 3G/K, 1680s after ignition.

Figure 3.14-17. Experiment 3G/K, 1775s after ignition.

Figure 3.14-18. Experiment 3G/K, 1820s after ignition.


**Figure 3.14-19. Experiment 3G/K, 1920s after ignition.**

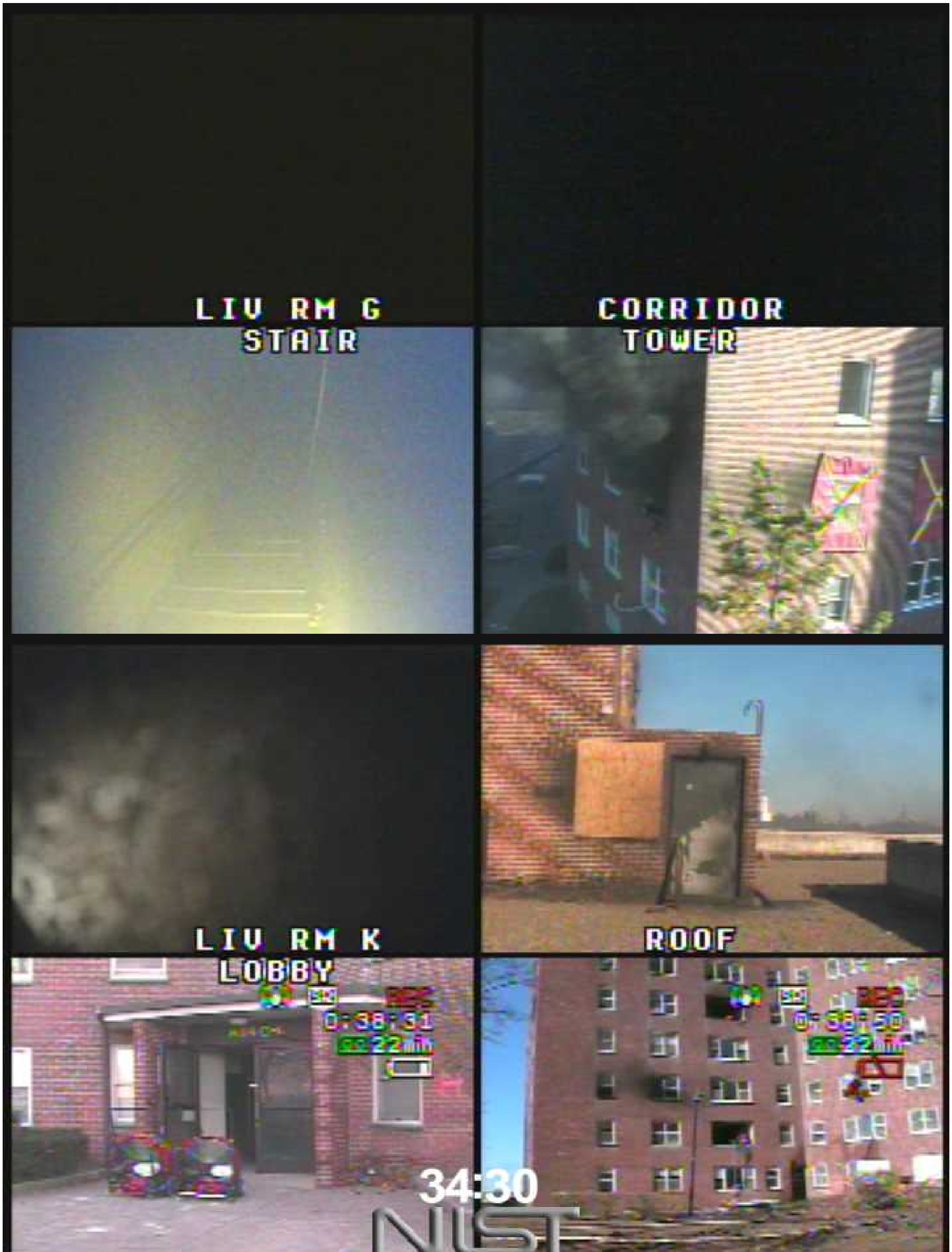


Figure 3.14-20. Experiment 3G/K, 2070s after ignition.


Figure 3.14-21. Experiment 3G/K, 2100s after ignition.

Figure 3.14-22. Experiment 3G/K, 2160s after ignition.

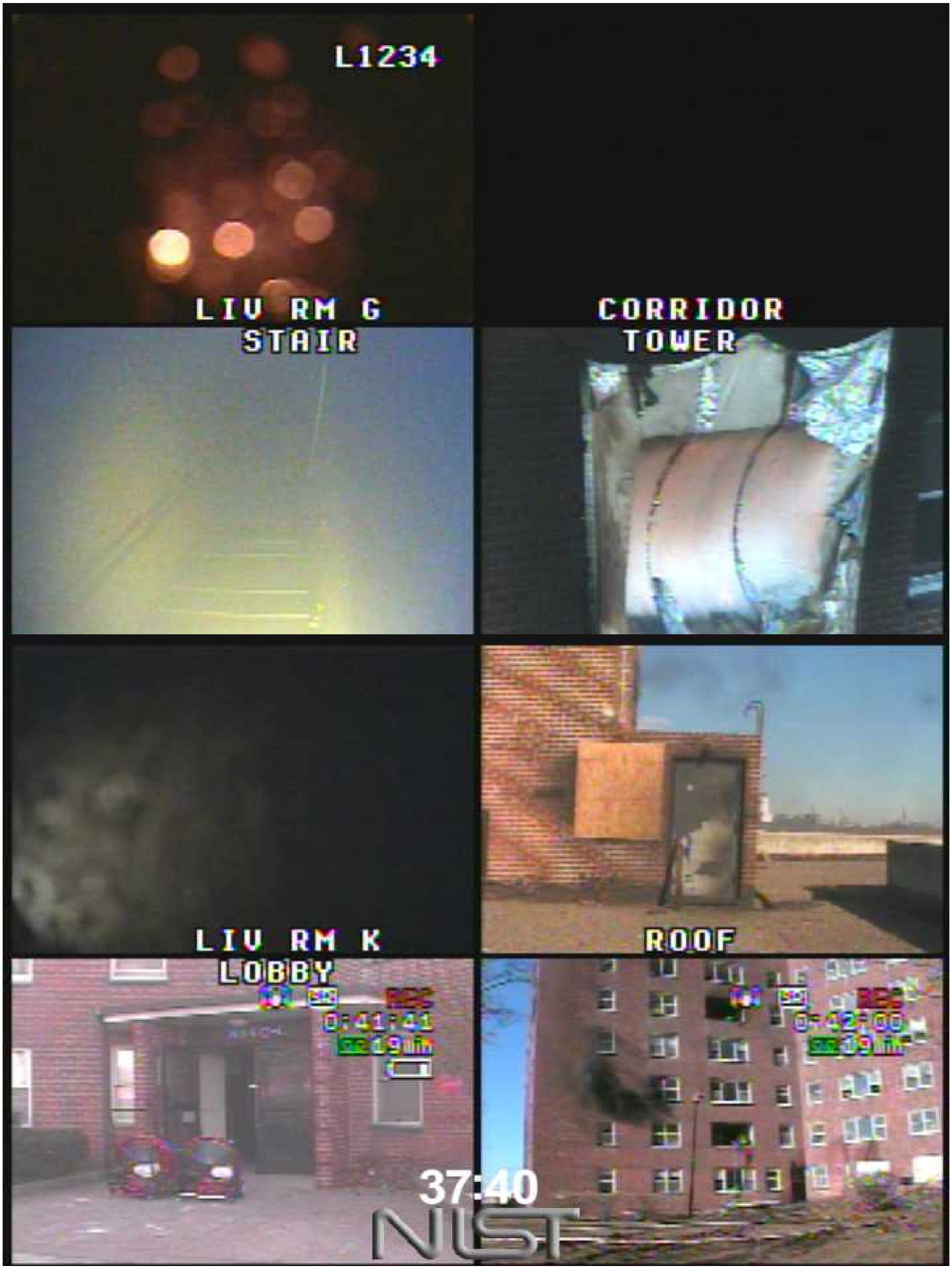


**Figure 3.14-23. Experiment 3G/K, 2260s after ignition.**


**Figure 3.14-24. Experiment 3G/K, 2400s after ignition.**

Figure 3.14-25. Experiment 3G/K, 2640s after ignition.

Figure 3.14-26.  Experiment 3G/K, 2685s after ignition.

Figure 3.14-27.  Experiment 3G/K, 2715s after ignition.


**Figure 3.14-28. Experiment 3G/K, 2880s after ignition.**

### 3.14.2 Temperatures

Figure 3.14-29 through Figure 3.14-31 provide temperature data for several measurement locations on the fire floor at two elevations and throughout the height of the stairwell. The specific locations are identified with the description of each graph. The locations of the measurement positions can be seen in Figure 3.14-2. The events that occurred during the experiment are listed on the top of the figures with lines at the time of the event. A time history for each thermocouple at each measurement location is located in Appendix D – Detailed Graphs.

Figure 3.14-29 shows the temperatures versus time at 3 measurement locations; the bedroom, just outside the fire apartment in the corridor, just outside the A stairwell doorway. In this graph the bedroom data was measured at 1.8 m (6 ft) above the floor and the corridor positions were measured at 2.1 m (7 ft) above the floor. The bedroom temperature time history was very similar to the previous experiments in that the temperature increased to a peak range of 400 ºC (752 ºF) to 500 ºC (932 ºF) and then became ventilation limited. As portions of the upwind bedroom single window failed the temperature decreased, again similar to previous experiments. A difference here was that once the bedroom single window failed, a horizontal flow path existed from the bedroom in apartment 3G to apartment 3K; however this did not provide enough ventilation to enable the bedroom to transition to flashover. In previous cases, opening the bulkhead door led to flashover. In this case the natural wind impacted the entire building. The predominant flow was down and out the front lobby. Closing the bulkhead coincided with the transition to flashover. Post flashover, the temperatures in the bedroom began to follow previous experiment trends again, with the temperatures remaining high until suppression.

The temperatures in the corridor reached peak temperatures in the range of 300 ºC (572 ºF) to 400 ºC (752 ºF) following flashover in the bedroom. These temperatures remained fairly stable until the living room window was vented. This event was followed by the failure of the bedroom double window. The resulting wind flow reduced the temperatures in the corridor to less than 100 ºC (212 ºF). The temperatures in the corridor increased to approximately 200 ºC (392 ºF) once WCDs were deployed to block the natural wind and the simulated wind from the MVU turned the flow around and pushed the hot gases back through the apartment. Once the living room transitioned to flashover, the temperatures in the corridor exceeded 600 ºC (1112 ºF). After removing the simulated wind, the corridor temperatures decreased to approximately 200 ºC (392 ºF). Use of the FBN in the bedroom resulted in a temperature increase in the corridor. suppression in the living room with the FBN results in all temperatures on the fire floor decreasing to approximately 100 ºC (212 ºF).

Figure 3.14-30 shows the temperatures versus time at 3 measurement locations; the bedroom, just outside the fire apartment in the corridor, and just outside the A stairwell doorway at 1.2 m (4 ft) which would be more representative of where firefighters would be operating or occupants would be evacuating. The bedroom and corridor positions track well with the temperatures closer to the ceiling.

Figure 3.14-31 shows the temperatures 1.2 m (4 ft) above the landing on floors 1, 2, 6 and at the bulkhead landing above the 7th floor with access to the roof. The highest temperatures occurred when the bulkhead door was closed and they occurred at the two floor levels below the fire floor since prior to the failure of multiple windows in the fire apartment, the predominant flow path was down the stair way and out the front doors. After the bulkhead door was opened, and the PPV fans were turned on, all of the temperatures decreased to less than 25 ºC (77 ºF) for the remainder of the experiment. This experiment was different from the other experiments with regard to the bulkhead and ventilation in that the wind was pushing fresh air into the bulkhead door. As a result it did not function as a hot gas exhaust vent but as a cool air intake port.

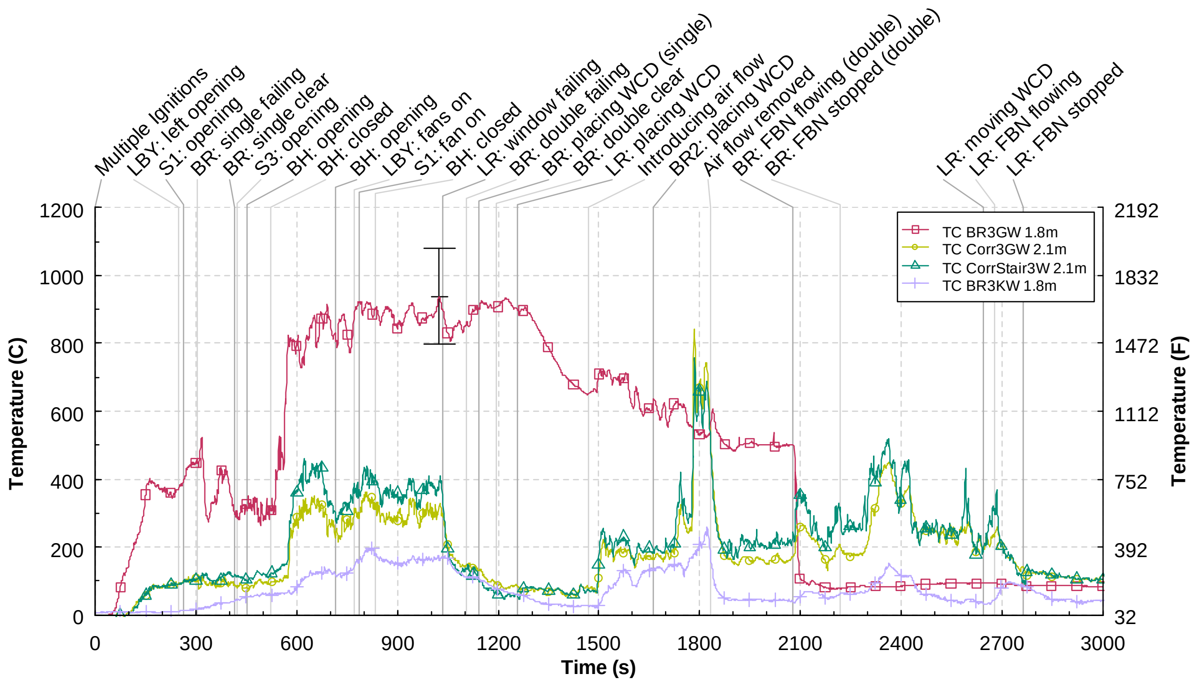



**Figure 3.14-29. 3G/K Temperature vs. time at 2.1 m above the floor**

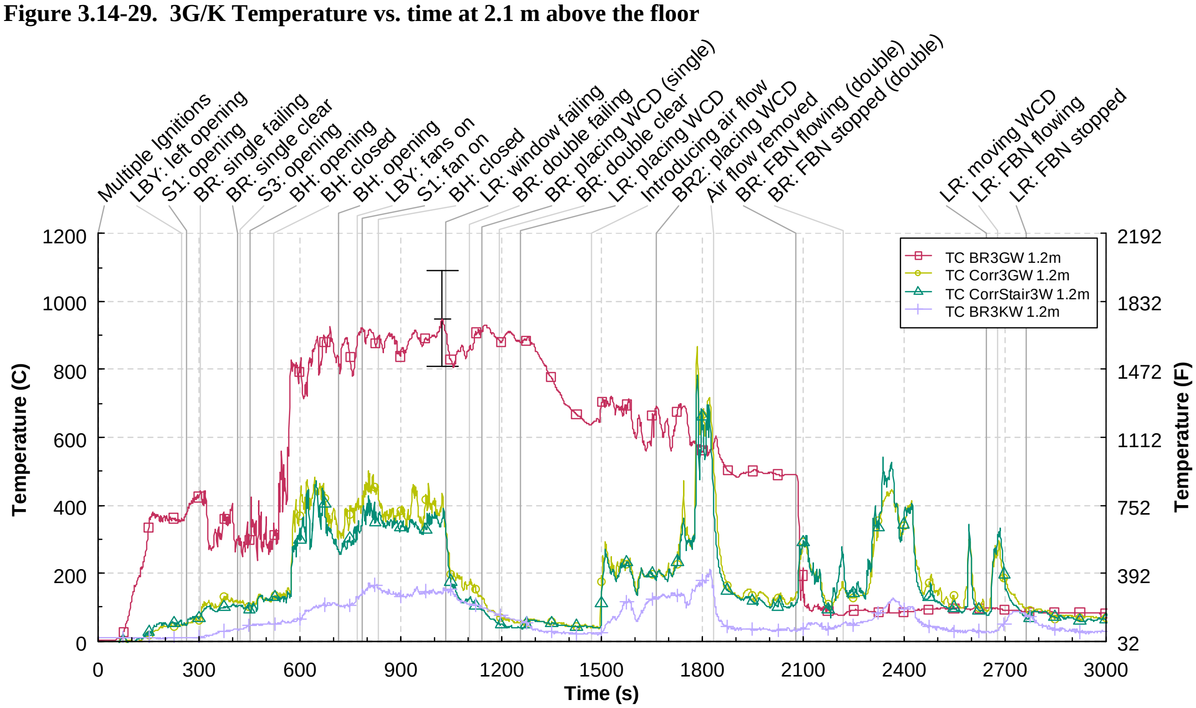



**Figure 3.14-30. 3G/K Temperature vs. time at 1.2 m above the floor**

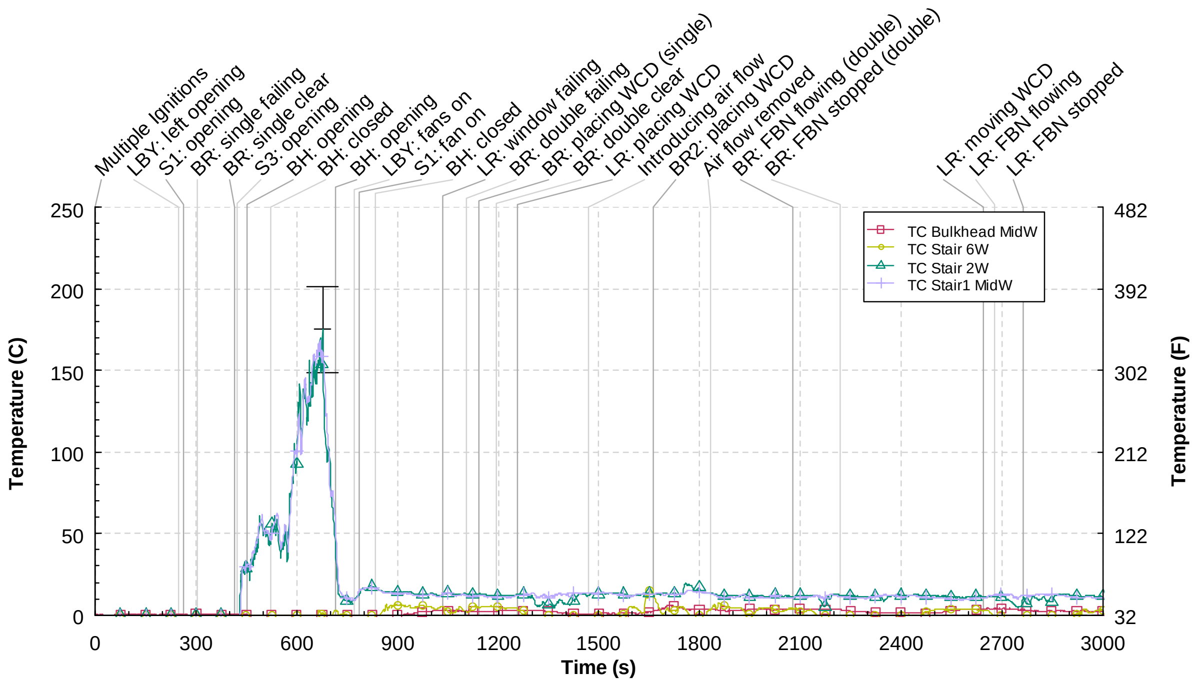



**Figure 3.14-31. 3G/K stairwell temperature vs. time**

### 3.14.3 Pressures

Average pressure measurements in the stairwell are shown in Figure 3.14-32. The differential pressure measurements were made at 1.2 m (4 ft) on the stairwell landing of every floor and referenced to an apartment on the same floor. With all of the doors to the stairwell closed the pressures remained within ± 10 Pa. Opening the lobby and stair door on the 1st floor (on the downwind side of the building) reduced the pressures in the stairway. Opening the stair door to the fire floor resulted in increased pressures above the fire floor, while the pressures stayed low below the fire floor. Once the PPV fans were used, the pressures increased in the stairwell and for each of the positions remained relatively steady through the remainder of the experiment. The exception was the pressure measurement on the fire floor which had swings between -30 Pa and 25 Pa, due in part to the multiple openings on the fire floor, and the methods attempted to control the wind flows.

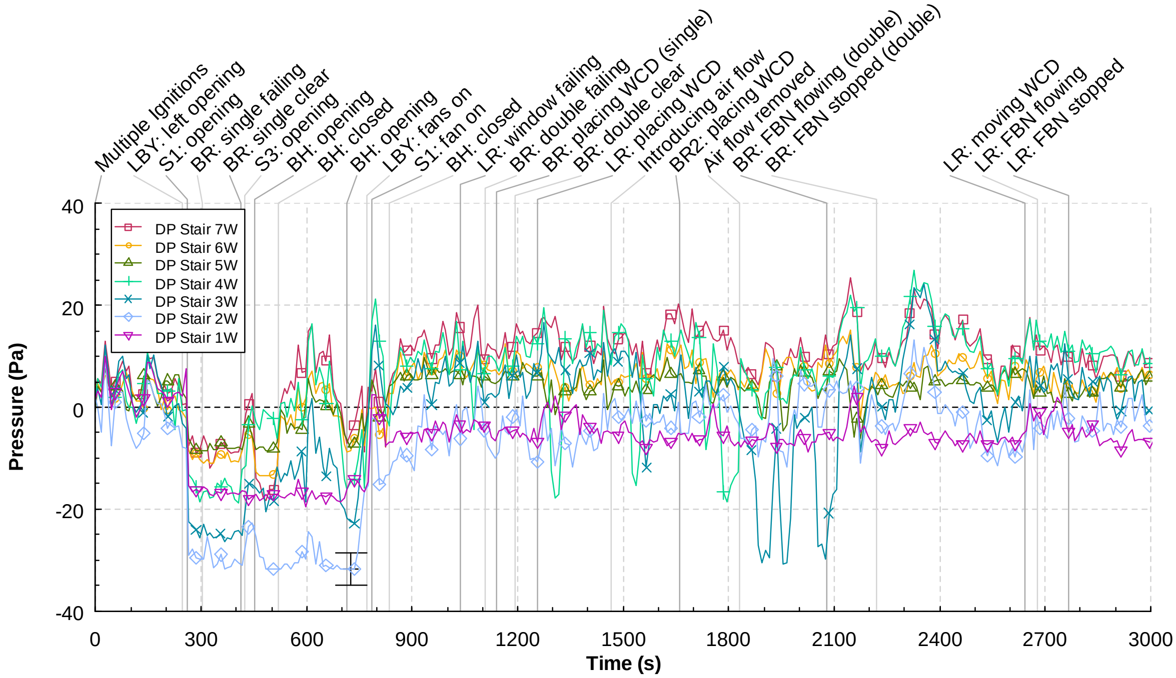



**Figure 3.14-32. 3G/K stairwell pressures vs. time**

### 3.14.4 Discussion

This experiment was unique in this series of experiments, in that it had a natural wind condition that had an effect on the entire structure. Yet in many respects the results of this experiment were similar to the results of the experiments with a simulated wind that was only imposed on one window.
The fire developed and became fuel rich or ventilation limited. After the window self vented and the bedroom transition to post flashover conditions, the resulting thermal conditions were not conducive to a direct frontal fire attack and firefighters remote from the fire in the corridor would have been threatened if they were in the flow path due to extreme temperatures.

The wind completely changed the flow path in the stairwell for this experiment. No hot gas or smoke was vented out of the bulkhead doorway on the roof in this experiment. This was counter to the experience in the other experiments, where opening the bulkhead door resulted in flashover. In this experiment, the wind pushed the flow down the stairs and out the front lobby doors, which were on the downwind side of the building.

The self venting of the bedroom double window demonstrated how building arrangement and wind conditions may exist such that, by venting other windows in the fire aparment, the wind driven fire can be vented out of the building, reducing the hazardous conditions in the public corridor and the stair. The concern here would be the lack of control if the wind were to change abruptly.

PPV fans were used successfully to stop the downward flow and clear the stairwell. In this experiment, as is generally true, door control and co-ordination were the keys to the successful use of PPV.

In this experiment, the WCDs were used more as tools to "replace the vented windows" for the experiment rather than for a fire fighting tactic. This experiment did create a significant thermal exposure for the WCD over the bedroom and living room windows, including exposure to direct flame impingement. In both cases, the WCDs continued to maintain their functionality throughout the experiment and blocked the wind.

The FBN 1 was discharged into both the bedroom and the living room and suppressed the fires in a short period of time, resulting in conditions in the corridor which would have allowed firefighters in full PPE to have safe access to the fire floor.

The fire did not spread to Apartment 3K. The peak temperature measurements in the most remote bedroom, furthest distance from ignition on the flow path at 1.2 m (4 ft) above the floor, were approximately 150 ºC (302 ºF) during the natural wind portion of the experiment and were approximately 200 ºC (392 ºF) during the simulated wind portion of the experiment. Clearly untenable conditions for unprotected building occupants and potentially hazardous conditions for protected fire fighters. Removing the air reduced the temperatures in this remote room to less than 50 ºC (122 ºF) within seconds. During the suppression of the living room fire, the temperatures in the bedroom increased to nearly 100 ºC (212 ºF), indicative of steam flowing toward the open windows in the bedroom.

# 4 Discussion

The overall objective of this study was to improve the safety of firefighters and building occupants. If fire conditions in the building are such that fire fighters can not safely do their job, clearly the options available to the occupants will be limited and they will be at great risk. A means to evaluate the effectiveness of PPV, WCD and/or externally applied water is to examine the tactic's capability to mitigate the hazard and provide survivable conditions in the stairwell and corridor for firefighters in full PPE. To assess these conditions and the effectiveness of the tactics, a brief discussion of firefighter tenability is required.

The fire environment provides many challenges; reduced visibility, toxic combustion products, thermal energy and potential for structural collapse. Since a fire resistive building was used in this study, the challenges are limited to the first three items listed above. Firefighters may be equipped to deal with these challenges with thermal imagers to improve visibility, self contained breathing apparatus (SCBA) to protect against the combustion products for a limited time, and PPE to absorb thermal energy for a limited time. How long the PPE can protect the firefighter from a thermal injury is based on many factors; thermal storage capacity of the gear, condition of the PPE, moisture content of the PPE, fit of the PPE, insulation under the PPE (station uniform), and the rate of energy (heat) transfer to the PPE.

The rate of heat transfer is of predominate interest in examining the results of these experiments. Unfortunately there is no single measure, as the heat is transferred in different ways. The two principle means of heat transfer of concern here are convection which is a function of the gas temperature and gas velocity and radiation which is a function of the gas temperature and the composition of the fire gases. In the wind driven tests post-window failure, the majority of the heat transfer, even in positions near the floor is a combination of convection and radiation. In other words, hot fire gases flowing over a firefighter and hot gases and/or hot surfaces in the compartment radiating energy to the firefighter. One of the more extreme examples of this combination of convective and radiative heat transfer is direct flame impingement.

In the ideal situation PPE is designed to protect a firefighter from temperatures up to 260 ºC (500 ºF) for 5 minutes [47]. However, that does not account for the heat flux that the PPE is exposed to along with the elevated temperature, nor the increased rate of heat transfer due to the relatively high velocity convective flows. Just prior to flashover, the heat flux from the upper hot gas layer to the floor approaches 20 kW/m$^2$. Post-flashover heat flux conditions range from 60 kW/m$^2$ to more than 160 kW/m$^2$. Based on previous research at NIST, a firefighter in full PPE, exposed to temperatures in excess of 260 ºC (500 ºF) combined with heat fluxes in excess of 20 kW/m$^2$ suggest that survival time would be limited to less than 30 s [48, 49, 50]. In these experiments, during a wind driven condition, temperatures on the order of at least 400 ºC (752 ºF) occurred in the corridor and portions, prior to using one of the mitigating tactics, indicating that conditions in the corridor and portions of the stair may not be not survivable for a firefighter in full PPE.

The first two experiments (7G and 7G2) were conducted without an imposed wind condition to examine the development of the fire and the impact of PPV. The next eleven experiments were conducted with simulated wind of 9 m/s to 11 m/s (20 mph to 25 mph), typically imposed on a window in the room of fire origin. These experiments were used to develop wind driven fire conditions in the structure and then examine different means of controlling the flow path through the structure, i.e. doors, fans and

WCDs, to mitigate the hazard. Suppression tactics using appliances from the floor below were also examined in these experiments.

The last experiment (3GK) was focused mainly on horizontal flow path from the upwind side of the building to the downwind side. For this experiment, natural wind was available and was used. The MVU driven flow was also used in the latter part of in this experiment.

Each of the experiments had a list of objectives that were to be examined. In this section, those objectives will be examined across the experimental series and examples will be given focusing on the specific tactic or tactics used. The effectiveness will be examined mainly in terms of temperature, but velocity and pressure will also be considered as the conditions are related and references will be made back to the specific figures in the experiment.

**Wind driven fire conditions** – The wind driven condition can be described as hot gases or flames flowing horizontally out of the room of fire origin. The wind driven fire condition has been described as a "blow torch". For our purposes, a wind driven fire condition was when the fire gases were well mixed and of equally high temperature from the floor to the ceiling, on the order of at least 400 ºC (752 ºF). This condition was generated in eleven of the fourteen experiments. The three exceptions were experiments 7G, 7G2 and 5E. Experiments 7G and 7G2 were conducted with no imposed external wind, hence no wind driven fire condition. Experiment 5E had an imposed wind on the upwind window of the fire room, however a WCD was deployed prior to window failure, as a result there was no wind driven fire condition in Apartment 5E.

An example of the uniform floor to ceiling temperatures is given below in Figure 4-1. These temperature measurements show the first 400 s after ignition at the corridor location outside of apartment 7K. The fire was started in the bedroom, approximately 15 m (50 ft) away from the measurement location. The temperatures increased gradually and they were stratified with the hotter gases near the ceiling. Once the flow path was completed by opening of the bulkhead door on the roof, temperatures from floor to ceiling increased to approximately 600 ºC (1112 ºF) within seconds. These hot gases which were typically flowing with velocities of 5 m/s (11 mph) or more are lethal to firefighters in full PPE. There is no safe position to "get low and let it blow" since the hot gases are well mixed and nearly uniform in temperature from floor to ceiling. Hence, it is critical that firefighters do not get caught in the flow path, downwind of a wind driven fire.

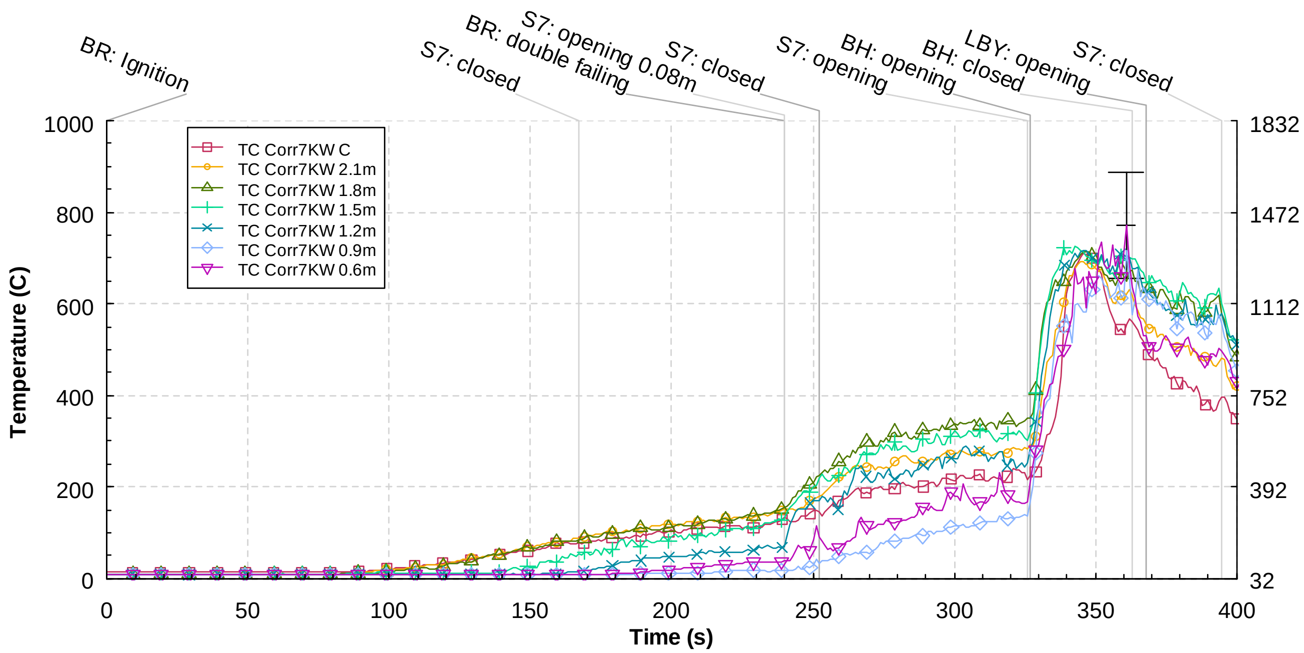



**Figure 4-1. Temperature vs time from the vertical thermocouple array at the corridor position outside of apartment 7K.**

If the flow path is favorable to an interior attack, the heat will be forced out of the structure by the wind and the cool air will be at the firefighters back as they approach the fire. Conditions adverse to an interior attack will be developed when the flow of air is into the structure through the fire room, such that heat is forced into the structure by the wind or the building ventilation path. In these cases, the flames or hot gases will meet the firefighters head on. In order for this condition to exist a number of conditions have to be met; a ventilation limited fire, which generated significant quantities of excess fuel in the form of combustion products, additional fuel down wind of the room of origin and most importantly a flow path. Without a flow path, the wind driven fire condition can not occur.

## 4.1 Door Control

Door control is the most basic means to control the flow path in the building. Figure 4.1-1 and Figure 4.1-2 show the impact of the opening and closing doors in the flow path. Figure 4.1-1 shows a portion of the temperature time history from Experiment 5E2. Time "zero" equals the beginning of window failure. At this point in time a flow path exists through the apartment into the stairwell and up to the open bulkhead door. At approximately the 70 s mark, the majority of the living room window had self vented and the living room has transitioned to a post-flashover condition with flames floor to ceiling. Post-flashover, all of the temperature measurements at 1.2 m (4 ft) above the floor along the flow path on the fire floor were in excess of 400 ºC (752 ºF). Once the bulkhead door was closed, the wind driven condition stopped. This experiment was challenging because the living room was still able to get air from other open windows in the apartment, therefore the living room continued to burn but the flow of hot gases into the corridor and stairwell slowed down. Just prior to the bulkhead door being closed, the velocity of the hot gas flowing out of the bulkhead was approximately 10 m/s (22 mph) and the temperature at the bulkhead was over 1000 ºC (1832 ºF), Figure 3.7-15 and Figure 3.7-17. Within seconds of closing the bulkhead door, the velocity at the bulkhead was reduced to 0 m/s and within 90 s the temperature at the bulkhead had decreased to approximately 200 ºC (392 ºF).

However, the thermal conditions on the fire floor were decreased slowly due to the continued burning in the living room. PPV fans were turned on at the lobby doors, however, with the bulkhead door closed and the imposed wind still blowing into the apartment, the pressures in the stairwell at the fire floor were in the 50 Pa to 60 Pa range, more than the fan at the position could overcome, Figure 3.7-16.

A FBN 1, flowing approximately 160 gpm with a narrow fog pattern, was discharged into the living room window opening. After a few seconds of adjustment, water flowed into the living room and temperatures on the fire floor were reduced to approximately 100 ºC (212 ºF) within 70 s.

These results demonstrated that closing a door to interrupt the flow path, even a door remote from the fire floor, in this case the bulkhead door, can stop the wind driven flow condition. However, the further the door is away from the fire apartment the larger the area that may still be filled with hot gases (stored fuel and energy). In this experiment, applying water from the floor below was needed to control the fire in the living room and dissipate the heat on the fire floor, thus rendering the area safe for further firefighter operations.

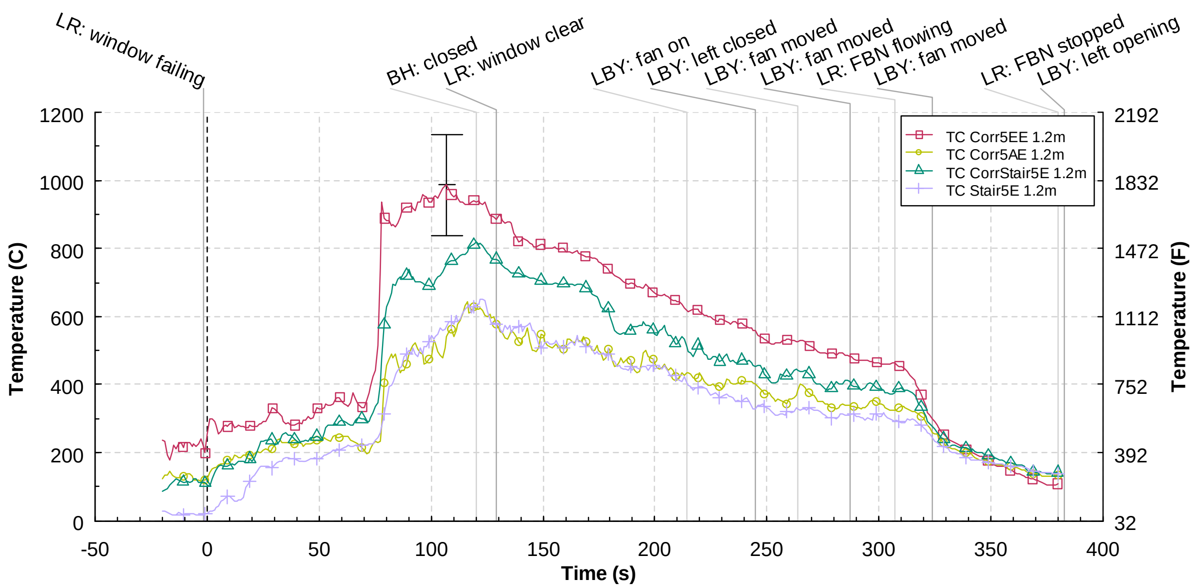



**Figure 4.1-1. Temperature vs time, several locations on the fire floor at 1.2 m (4 ft) above the floor, experiment 5E2. T=0 is the time of the beginning of window failure.**

Experiment 5G2 demonstrated the impact that opening doors to create a flow path can have on the development of wind driven conditions. Figure 4.1-2 shows a portion of the temperature time history from experiment 5G2, where time zero is defined at the time that the door to the stairwell on the fire floor was opened. By opening that door, a flow path was developed that went from the open living room window through the stairwell and down through the open 1$^{st}$ floor stair door to the outside. As a result this action increased the temperature in the stair on the fire floor and at adjacent floors above and below the fire floor by approximately 100 ºC (212 ºF), Figure 3.11-15. The hot gas velocity flowing out of the apartment and into the stair were approximately 2 m/s (4 mph) as a result of the stair door opening on the fire floor and flow out of the stairwell at the 1$^{st}$ floor was about 1 m/s (2 mph).

Approximately 20 seconds later the bulkhead door was opened. This gave the buoyant hot gases a flow path that was up and out. Within 30 s of the opening of the bulkhead door, temperatures in the flow path on the fire floor had exceeded 600 ºC (1112 ºF). Temperatures in the stairwell above the fire floor increased to almost 600 ºC (1112 ºF) at the 6th floor landing and 400 ºC (752 ºF), Figure 3.11-15. The velocity of the hot gases flowing out of the apartment and into the stairwell increased to approximately 6 m/s (13 mph), Figure 3.11-17.

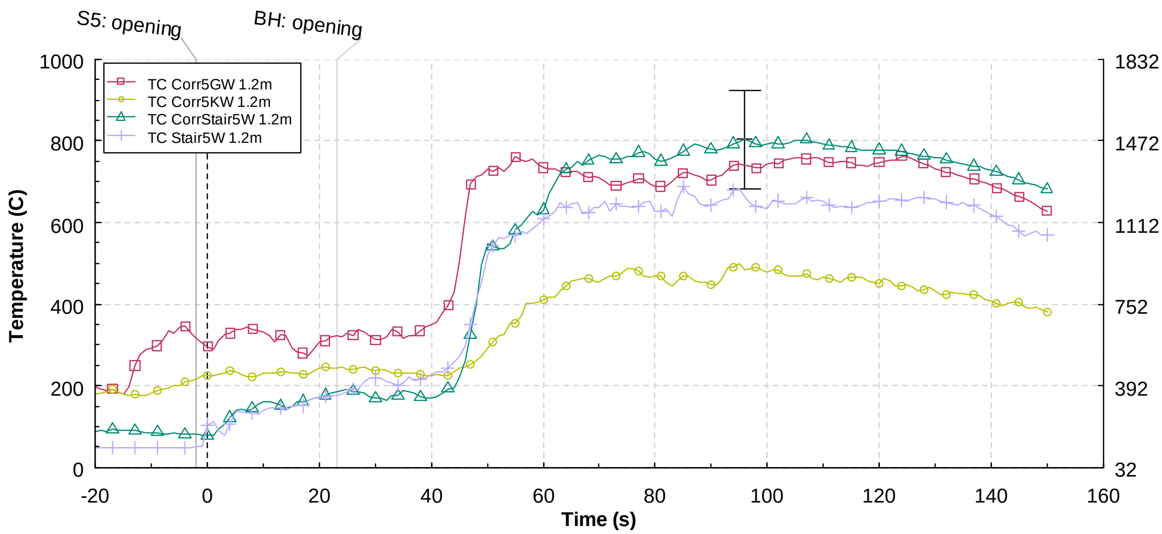



**Figure 4.1-2. 5G2 Temperature vs time, several locations on the fire floor at 1.2 m (4 ft) above the floor. T=0 is the time of opening the 5th floor stairwell door.**

## 4.2 PPV fans to control smoke movement

As documented in several previous studies [39,40], PPV fans can be used effectively in high rise buildings to pressurize stairwells to protect them from the inflow of combustion products based on the natural pressures that are generated from fire. Figure 4.2-1 and Figure 4.2-2 provide examples of the impact that a single 27 inch PPV fan can have on the temperatures in the stairwell from a non-wind driven fire on the 7th floor, during experiments 7G and 7G2 respectively. In each case, time zero equals the time that the fan team had the fan in place, started and operating at maximum rpm. With cool air from outside the structure being forced into the stairwell, the temperatures decreased to near ambient temperatures on the fire floor level within 60 s of activation.

It has also been noted in many of the wind driven experiments that one or two 27 inch PPV fans could not exceed the pressures generated by a wind driven fire condition. In experiment G2, with one fan operating on the 1st floor and one fan operating on the 5th floor with the bulkhead door closed and the fire floor door open stairwell pressures were in the range of 15 Pa to 30 Pa.

In comparison, experiments 5A and 5G had imposed wind conditions. With the 1st floor and 5th floor (fire floor) doors open to the stairwell and the bulkhead door closed, the differential pressures at the fire floor and up exceeded 40 Pa.

The key to successful use of PPV fans is to mitigate the wind driven fire condition via door control or other tactics. Then the PPVs can be used to clear the stair and then pressurize the stairwell to provide a safe working environment. Even if the PPV fans, when used alone, could not reverse the flow of a wind driven fire, they always improved conditions in the stairwell.

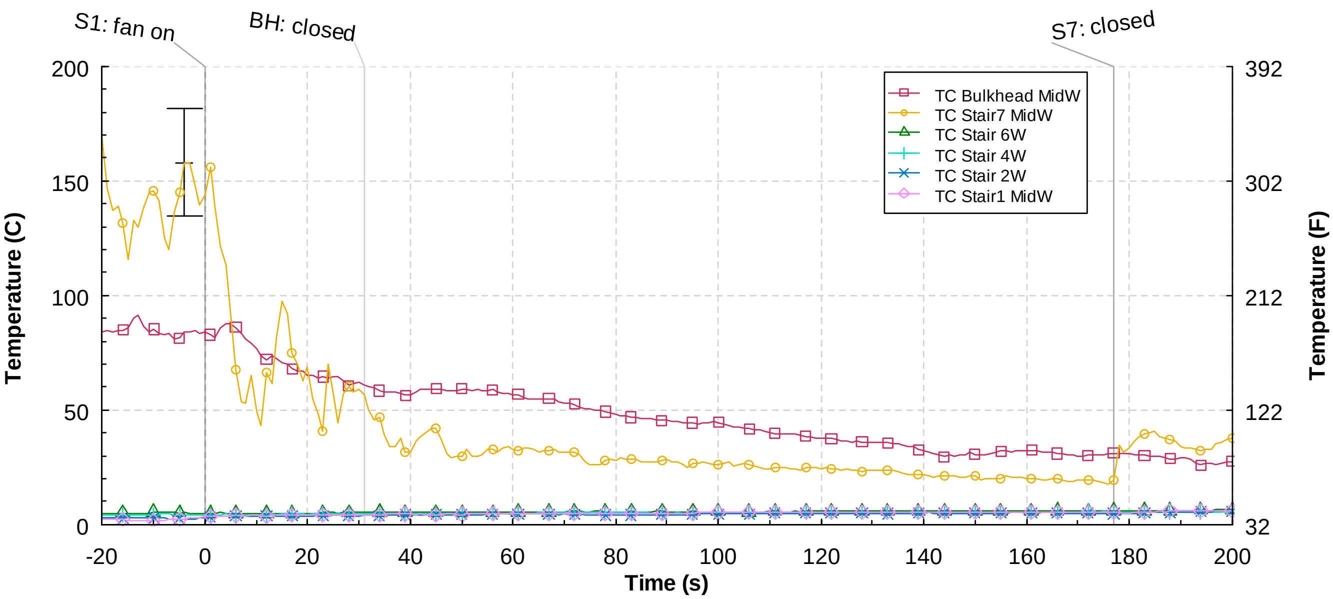



**Figure 4.2-1. 7G Stairwell temperature vs time. T=0 is the time that the fan was operating at the 1st floor doorway to the stairwell.**

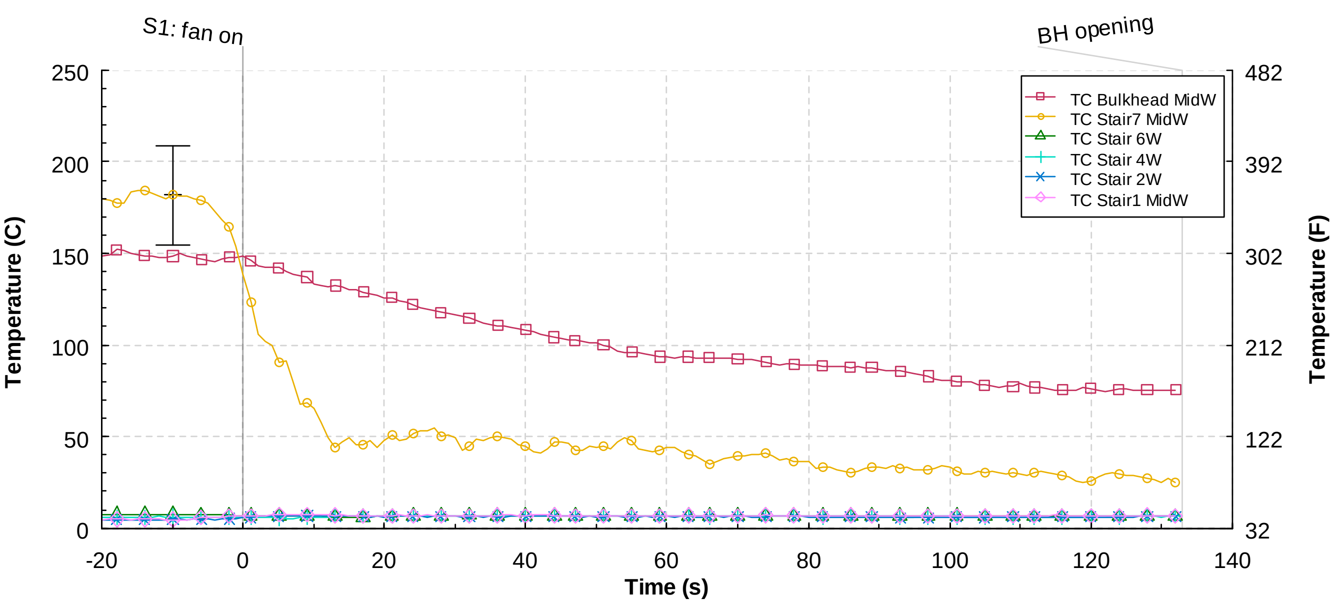



**Figure 4.2-2. 7G2 Stairwell temperature vs time. T=0 is the time that the fan was operating at the 1st floor doorway to the stairwell.**

## 4.3 WCD to control wind driven conditions

As discussed earlier, if the flow path can be interrupted, wind driven fire conditions cannot exist. All of the WCDs used in this study and in previous studies [1, 40] demonstrated that they were effective interrupting the flow path and were able to withstand the fire conditions to which they were exposed without failing. Once the WCD was deployed and covered the window completely, the flow path was interrupted, the velocities in the flow path decreased, and the wind driven condition stopped. As shown below in Figure 4.3-1, the firefighters would then be faced with the residual fire and stored energy (hot gases and hot walls, ceiling and floor) and fuels (smoke and remaining furnishings or interior finish) in the structure.

Figure 4.3-1 and Figure 4.3-2 demonstrate the impact that WCDs can have on a post flashover wind driven fire environment. Time zero is the point in time that the WCD was in place for each experiment. In both figures is can be seen that the temperatures began to decrease at locations remote from the room of origin almost immediately. Within 120 s of deployment, the temperatures had decreased by at least 50% from the temperatures at the time of WCD deployment.

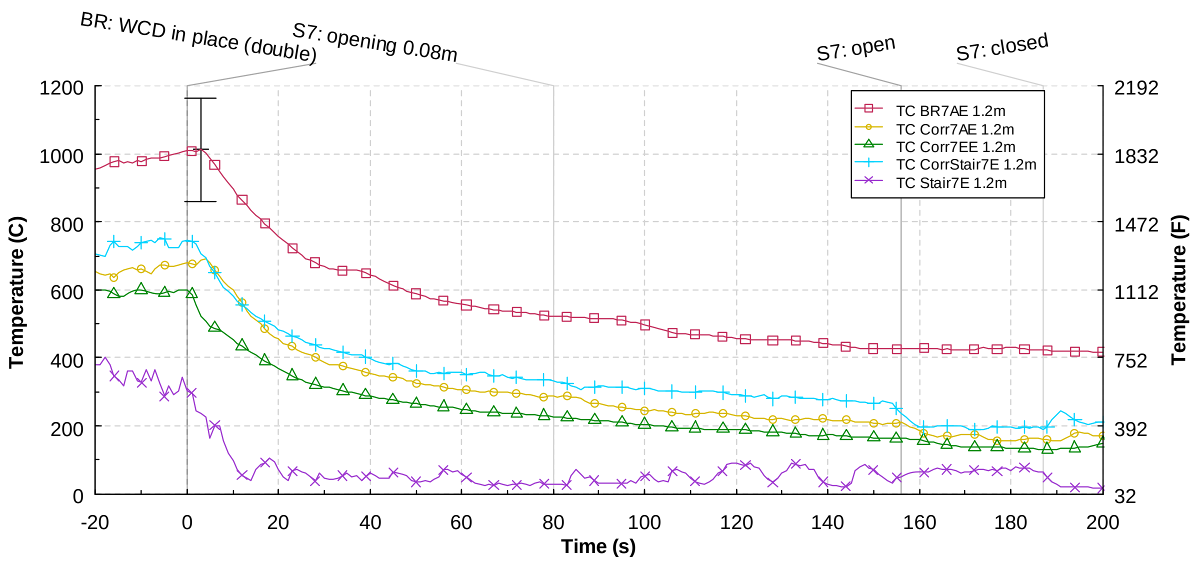



**Figure 4.3-1. 7A Temperature vs time at 1.2 m above the floor. T=0, is the time that the WCD was deployed.**

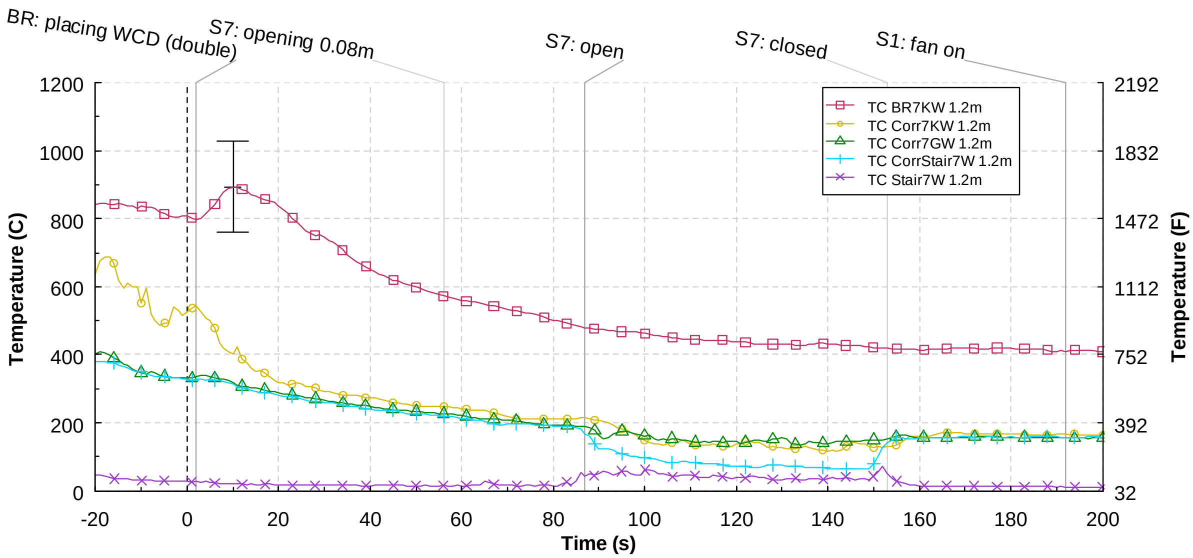



**Figure 4.3-2. 7K Temperature vs time at 1.2 m (4 ft) above the floor. T=0, is the time that the WCD was deployed.**

## 4.4 FBN to control wind driven conditons

The results of the experiments with the FBN demonstrated that a relatively small amount of water flow, 125 gpm to 200 gpm had a significant effect on suppressing the fire in the room of origin and reducing the temperatures downwind of the fire apartment. In the case of the FBNs or externally applied water, the temperature reductions were the most significant in the room of fire origin, reducing the temperatures to approximately 100 ºC (212 ºF) within 60 s of the start of suppression. Figure 4.4-1 and Figure 4.4-2, from experiments 3A and 5K respectively, show the temperatures at 1.2 m (4 ft) above the floor in the bedroom (room of fire origin) and outside of the fire apartment at locations in the corridor and in the stairwell on the fire floor. In Experiment 3A, Figure 4.4-1, the post flashover wind driven fire was suppressed with FBN1, which was fitted with a 1-1/8$^{th}$ inch smooth bore tip, and flowing approximately 160 gpm of water. Notice that after the initial bedroom fire was suppressed, the water flow was stopped and the FBN was moved to suppress the fire that the wind had spread to the living room. This provided additional reductions in temperatures on the fire floor.

Figure 4.4-2 shows a similar scenario from Experiment 5K. In this experiment FBN1 was fitted with an adjustable fog tip. The nozzle was adjusted to a narrow setting of approximately 30º and had a flow rate of 160 gpm. Again, the nozzle provided rapid suppression of the bedroom. The fog stream did not have as much impact downstream as did the solid stream when bounced off the ceiling. Just as in 3A, the FBN was moved to suppress the fire that the wind had spread to the living room. This further reduced the temperatures on the fire floor. In both cases, the FBN was able to reduce the hazards and provide a tenable environment for firefighters in full PPE.

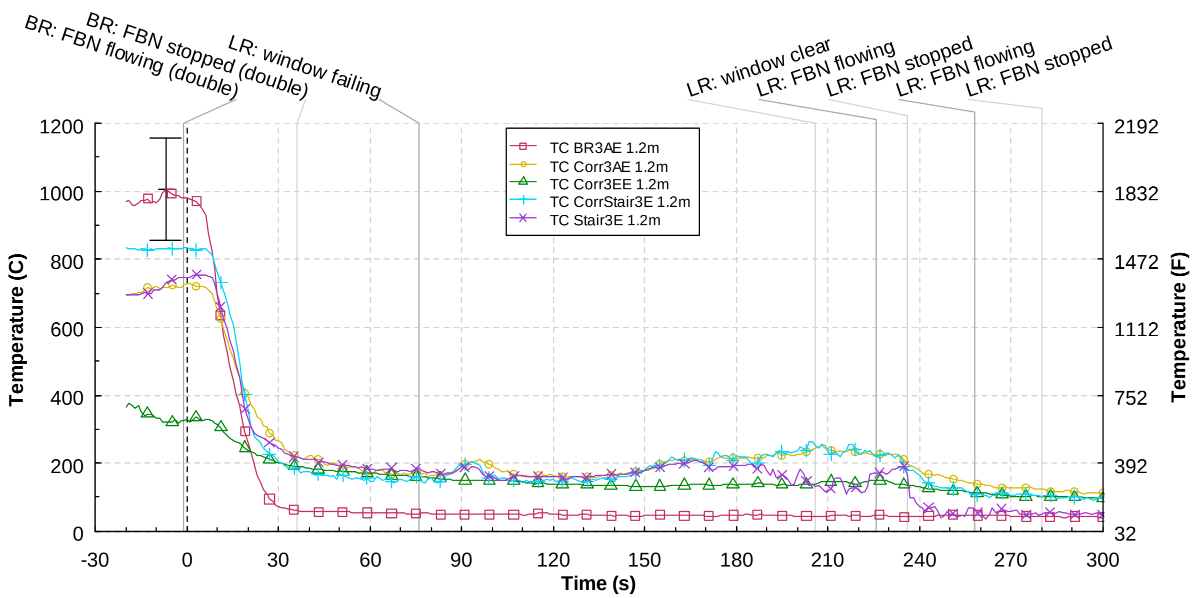



**Figure 4.4-1. 3A Temperature vs time at 1.2 m (4 ft) above the floor. T=0 is the time that suppression was started.**

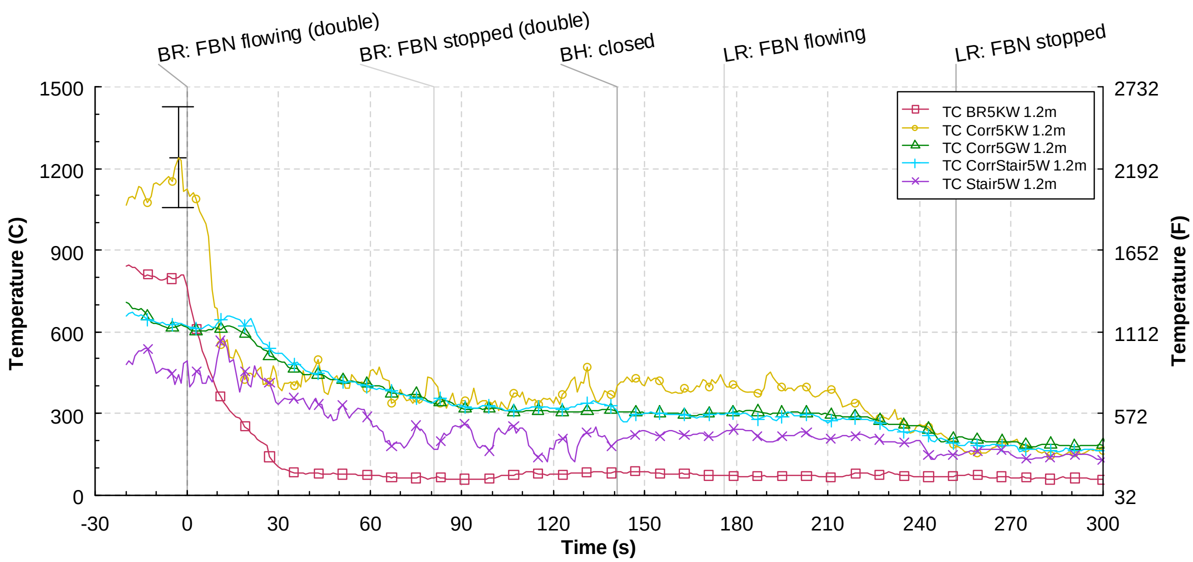



**Figure 4.4-2. 5K Temperature vs time at 1.2 m (4 ft) above the floor. T=0 is the time that suppression was started.**

## 4.5 Window Failure Time

The windows in the apartments were double pane, aluminum framed windows. Whereas the focus of the study was not on window construction or window failure modes, the data collected on window failure provides some insight. Only the failure times from the bedroom double windows is examined because those were the experiments in which the point of ignition was in the same location relative to the window and where the windows had not been previous exposed to fire conditions. These results are summarized in Table 4.5-1.

Based on what appeared to be a long time for window failure in Experiment 7G and since flashover and the wind driven conditions could not occur until the window failed, the inner pane of glass was removed for Experiment 7E. This resulted in a failure time of 163 s and appeared to delay the onset of flashover because of the early failure time. In both of these cases the gas temperature in the bedroom at 2.1 m above the floor, was approximately 500 ºC (932 ºF).

In the remaining experiments, the inner window pane was left in place, but the glass was scored with a glass cutter to increase points of stress to incur earlier failure of the inner pane. In these cases the failure times ranged from a low of 233 s to a high of 496 s and averaged 342 s. Gas temperatures in the room, near the ceiling, at the time of failure, ranged from 300 º C (572 ºF) to 700 º C (1292).

In each of the experiments, it appeared that flames made contact with the windows prior to failure of the glass. The failure of the glass was one of the enabling events for the wind driven fire condition inside the structure, as it served as the fresh air inlet to any potential flow path that might evolve based on opening of doors or other windows.

**Table 4.5-1. Failure Time of Bedroom Double Window and Approximate Upper Layer Gas Temperature**

| Experiment | Time to Initial Failure (s) | Approximate Gas Temperature (º C) | Comments |
|---|---|---|---|
| 7G | 344 | 550 | no wind |
| 7E | 163 | 550 | inner pane of glass removed |
| 7A | 316 | 400 | Inner pane scored |
| 7K | 240 | 700 | 1.8m in BR, Inner pane scored |
| 5E | 233 | 550 | WCD pre-deployed, Inner pane scored |
| 5K | 303 | 550 | Inner pane scored |
| 5A | 234 | 500 | Inner pane scored |
| 5G | 425 | 300 | Inner pane scored |
| 3E | 493 | 550 | Inner pane scored |
| 3A | 496 | 550 | Inner pane scored |

# 5 Tactical Considerations

Fire departments that wish to implement the tactics used in this study will need to develop training and determine appropriate methods for deploying these tactics. Variations in the methods of deployment may be required due to differences in staffing, equipment, building stock, typical weather conditions, etc. There is uniformity however, in the physics behind the wind driven fire condition and the principles of the tactics examined. These are discussed below.

**Wind is a factor.** As shown in these experiments, wind can significantly increase the thermal hazards of a fire in a structure. Wind conditions will vary at different elevations above the ground floor, on different sides of a building, due to the effects of surrounding structures or topography, or just changes in the wind itself. Therefore wind needs to be considered as part of the intial "size-up" of the fire conditions and continue to be monitored and reported on throughout the fire incident.

**Smoke is Fuel.** A ventilation limited (fuel rich) condition developed prior to the failure of the windows. Oxygen depleted combustion products, containing carbon dioxide, carbon monoxide and unburned hydrocarbons, filled the rooms of the structure. Once the window failed, the fresh air provided the oxygen needed to sustain the transition through flashover, which caused a significant increase in temperature.

**Venting does not always equal cooling.** In these experiments, the cool air forced into the broken upwind window resulted in an initial period of cooling in the room of origin, typically followed by a transition to flashover, if a flow path was available.

**Fire induced flows.** Velocities within the structure exceeded 5 m/s (11 mph), just due to the fire growth and the flow path that was set-up between the window opening and the open bulkhead door on the roof.

**Avoid the flow path.** The directional nature of the fire gas flow was demonstrated with thermal conditions which were significantly higher in the "flow" portion of the corridor as opposed to the position remote from the flowpath**. Thermal conditions in the flow path were often higher than 400 ºC (752 ºF) and were not consistent with firefighter survival.**

**Control the flow path.** Wind driven conditions with untenable thermal conditions can not occur if there is no flow path through the structure. If the door to the stair on the fire floor is closed, the spread of fire and heat will be limited and wind driven "blow torch" conditions will not occur. In these experiments, after the fire room window had failed, opening the fire floor stair door and the bulkhead door, typically provided the flow path that led to wind driven "blow torch" conditions on the fire floor. Therefore it is importment to control and coordinate the opening and closing of doors in a structure. This study has also shown that WCDs, when deployed in a way to completely cover the window opening, were effective in mitigating the effects of the wind and controlling inlet of the flow path. The experiments demonstrated the importance of coordinating and controlling the opening and closing of doors, which could provide a flow path, to avoid placing fire fighters in the flow path. Fire fighter training would be beneficial to identify and prepare areas which could be used as safe areas of refuge, which are out of the flow path.

**Use of PPV.** Two 27 in PPV fans could not overcome the effects of a wind driven condition. However when used in conjunction with door control, WCDs, and FBNs (tactics that stop the wind driven condition) the PPV fans were able to maintain tenable and clear conditions in the stairwell. In these experiments, PPV use always improved conditions in the stairwell.

**Impact of WCDs**. In these experiments, the WCDs reduced the temperatures in the corridor and the stairwell by more than 50 % within 120 s of deployment. The WCDs also completely mitigated any velocity due to the external wind. The WCDs were exposed to a variety of extended thermal conditions without failure. The WCD must cover the window opening completely to be effective. Pre-deployment of a WCD over the fire room upwind window, prevented the development of wind driven fire conditions. The benefit of using a WCD, compared to using the apartment door or the stairwell door, is that the flow path is interrupted at the entry point. This improves all of the conditions along the entire potential flow path.

**Impact of externally applied water**. In these experiments, the externally applied water streams were implemented in different ways; a fog stream inserted into the fire room window, a fog stream flowed from the floor below into the fire room window opening, and a solid water stream flowed from the floor below into the fire room window opening. In all cases, the water flows suppressed the fires, thereby causing reductions of at least 50 % in temperature in the corridor and the stairwell. The water flow rates used in these experiments were between 125 gpm and 200 gpm, demonstrating that a relatively small amount of water directly applied to burning fuels can have a significant impact.

Wind driven fire conditions can generate and transfer energy throughout the flow path. When doors or WCDs are used to stop the wind driven fire conditions, energy and fuel may be trapped on the fire floor. These experimental results indicate that the thermal conditions due to the residual heat on the fire floor, were still of a level which could pose a hazard to firefighters in full PPE. However when used in combination with PPV fans to force cool air into the stairwell and out through the fire floor, and or with the cooling effect from water streams, the fire floor temperatures were reduced to tenable conditions for fire fighters in full PPE in minutes.

# 6 Future Research

The results from this series of full scale experiments in a 7-story, fire resistive building demonstrated that WCDs, and externally applied water streams, have the potential to reduce the hazard from a wind driven apartment fire. The resulting conditions in the corridor offered a fire environment with an improved level of safety for firefighters, although not an environment free from hazard. When PPV was used, the stair was cleared of smoke and hot gases.

The constraints of the fire resistive construction, used in these experiments, preclude insight on the response of ordinary or wood frame construction buildings to wind. For example, in the case of a wood framed structures, this study did not fully address all of the hazards that could be generated by a wind driven structure fire such as a shorter time until structural collapse. Therefore it is important to take the lessons from these experiments and the laboratory based experiments [1] to further advance the understanding of these tactics in the field. Experiments in real wood framed buildings with realistic fuel loads are required to further the understanding of the capabilities and limitations of implementing fire fighting tactics with PPV, WCDs and external hose streams in non fire resistive buildings.

## 6.1 Pilot Programs

FDNY has developed a training program on wind driven fires to educate their members about the importance of considering wind conditions when sizing up a fire, and to develop an understanding of flows within the building and how to control those flows with doors and PPV fans. Based on the outcome of the Governors Island experiments, FDNY has implemented a pilot program that includes training on tactics to mitigate wind driven fire hazards and deployment of PPV fans, WCDs and external hose streams which could be used in high rises. The Chicago Fire Department is planning to implement a pilot study on the use of PPV fans, WCDs, and external hose streams in the near future [51]

## 6.2 Standard Test Methods for Equipment

As the research and field trials continue, there are many commercially available products that are being examined and there are many prototype firefighting tools that are being offered for use in the experiments. If the technologies demonstrated continue to prove effective in the field trials and pilot programs, the next step may be to examine the need for standards and standardized test methods to define a minimum level of acceptable performance of these devices.

# 7 Summary

The National Institute of Standards and Technology (NIST), the Fire Department of New York City

(FDNY), and the Polytechnic Institute of New York University with the support of the Department of Homeland Security (DHS)/Federal Emergency Management Agency (FEMA) Assistance to Firefighters Research and Development Grant Program and the United States Fire Administration (USFA), have conducted a series of wind driven fire experiments in a 7-story, building on Governors Island, New York.

The objective of this study was to improve the safety of firefighters and building occupants by enabling a better understanding of wind driven fires and wind driven firefighting tactics, including structural ventilation and suppression. A series of 14 experiments were conducted to evaluate the ability of positive pressure ventilation fans (PPV), wind control devices (WCD) and floor below nozzles (FBN) to mitigate the hazards of a wind driven fire in a structure.

Each of the 14 experiments started with a fire in a furnished room. The air flow for 12 of the 14 experiments was intensified by a natural or mechanical wind. Each of the tools was evaluated individually as well and in conjunction with each other to assess the benefit to fire fighters, as well as potential occupants in the structure. The measurements used to examine the impact of the WCDs and the external water application tactics were temperature, differential pressure, and gas velocity inside the structure. Each of the experiments was recorded with video and thermal imaging cameras. These experiments also provided visual documentation of fire phenomena that are not typically observable on the fire ground.

The experiments were designed to expose a public corridor and stairwell area to a wind driven, post-flashover apartment fire. The door from the apartment to the corridor was open for each of the experiments. The conditions in the corridor and the stairwell were of critical importance because that is the portion of the building that firefighters would use to approach the fire apartment or that occupants from an adjoining apartments or adjacent floors would use to exit the building.

All of the fires were ignited in furnished rooms of an apartment. Due to excess fuel generation (or lack of ventilation) the room of fire origin could not transition to flashover until windows self-vented and introduced additional fresh air with oxygen to burn. Without a wind imposed on the vented window, the fire did not spread from the room of origin and never left the apartment of origin. Even with no externally applied wind, creating a flow path from the outside, through the fire apartment into the corridor and up the stairs to the bulkhead on the roof increased the temperatures and velocities in the corridors and in the stairwell to create hazardous conditions for fire fighters and untenable conditions for occupants on the fire floor and above in the stairwell.

With an imposed wind of 9 m/s to 11 m/s (20 mph to 25 mph) and flow path through the fire floor and exiting out of the bulkhead, temperatures in excess of 400 ºC (752 ºF) and velocities on the order of 10 m/s (22 mph) were measured in the corridor and stairwell above the fire floor. These extreme thermal conditions are not teneable, even for a firefighter in full protective gear.

These experiments demonstrated the "extreme" thermal conditions that can be generated by a "simple room and contents" fire and how these conditions can be extended along a flow path within a real structure when wind and an open vent are present. Potential tactics which could be implemented to interrupt and control the flow path are door control from inside the structure and or a WCD from the floor above the fire. From the floor below the fire, external water application was demonstrated to be effective in reducing the thermal hazard in the corridor and stairwell.

**Impact of PPV.** PPV fans alone could not overcome the effects of a wind driven condition. However when used in conjunction with door control, WCDs, and FBNs the PPV fans were able to maintain tenable and clear conditions in the stairwell.

**Impact of WCDs**. In these experiments, the WCDs reduced the temperatures in the corridor and the stairwell by more than 50 % within 120 s of deployment. The WCDs also completely mitigated any velocity due to the external wind. The WCDs were exposed to a variety of extended thermal conditions without failure.

**Impact of externally applied water**. In these experiments, the externally applied water streams were implemented in different ways; a fog stream inserted into the fire room window, a fog stream flowed from the floor below into the fire room window opening, and a solid water stream flowed from the floor below into the fire room window opening. In all cases, the water flows suppressed the fires, thereby causing reductions in temperature in the corridor and the stairwell of at least 50 %. The water flow rates used in these experiments were between 160 gpm and 200 gpm, demonstrating that a relatively small amount of water applied directly to the burn fuels can have a significant impact.

These experimental results also indicate that the post deployment thermal conditions for flow path control using a WCD, after the development of wind driven conditions, were still of a level which could pose a hazard to firefighters in full PPE. However, when used in combination with PPV fans to force cool air into the stairwell and out through the fire floor, and or with the cooling effect from an externally applied water stream, the fire floor temperatures can be reduced to near ambient conditions in minutes.

The experiments also provided potential guidance for firefighters as a part of a fire size up and approach to the room of fire origin: note wind conditions in the area of the fire, look for "pulsing flames", or flames not exiting a window opening, examine smoke conditions around closed doors in the potential flow path, and maintain control of doors in the flow path. Even if flames are being forced out of adjacent windows with a high amount of energy, there could still be sufficient energy flows on the fire floor to create a hazard for firefighters.

The data from this research will also help to identify methods and promulgation of improved standard operating guidelines (SOG) for the fire service to enhance firefighter safety, fire ground operations, and use of equipment. If the demonstrated technologies continue to prove effective in the field trials and pilot programs, the next step may be to examine the need for standards and standardized test methods to define a minimum level of acceptable performance of these devices.

# 8 References


1. Madrzykowski, D., and Kerber, S., Fire Fighting Tactics Under Wind Driven Conditions: Laboratory Experiments. National Institute of Standards and Technology, Gaithersburg, MD, NIST TN 1618, January 2009.
2. Hall, John, R., High-rise Building Fires. National Fire Protection Association, Fire Analysis and Research Division, 1 Batterymarch Park, Quincy, MA., August 2005.
3. Madrzykowski, D., and Walton, W.D., Cook County Administration Building Fire, 69 West Washington, Chicago, Illinois, October 17, 2003: Heat Release Rate Experiments and FDS simulations. National Institute of Standards and Technology, Gaithersburg, MD, NIST SP 1021, July 2004.
4. NIOSH F99-01, Three firefighters die in a 10-Story High-Rise Apartment Building – New York, NIOSH Fire Fighter Fatality Investigation and Prevention Program, Morgantown, WV., August 1999.
5. NIOSH F2001-33, High-Rise Apartment Fire Claims the Life of One Career Fire Fighter (Captain) and Injures Another Career Fire Fighter (Captain) – Texas, NIOSH Fire Fighter Fatality Investigation and Prevention Program, Morgantown, WV., October 2002.
6. http://www.nfpa.org/itemDetail.asp?categoryID=14398&itemID=34426&URL=Learning/Public%20education/Fire%20Prevention%20Week/About%20Fire%20Prevention%20Week. National Fire Protection Association, About Fire Prevention Week. Downloaded 9/11/08.
7. http://www.crh.noaa.gov/grr/history/?m=10&d=8 NOAA National Weather Service Weather Forecast Office, Weather History of October 8th. Downloaded 9/11/08.
8. NFPA 1051, Standard for Wildland Fire Fighter Professional Qualifications, National Fire Protection Association, 1 Batterymarch Park, Quincy, MA. 2007 ed.
9. NFPA 1001, Standard for Fire Fighter Professional Qualifications, National Fire Protection Association, 1 Batterymarch Park, Quincy, MA. 2008 ed.
10. NFPA 1021, Standard for Fire Officer Professional Qualifications, National Fire Protection Association, 1 Batterymarch Park, Quincy, MA. 2003 ed.
11. Andrews, P.L.; Bevins, C.D., Seli, R.C., BehavePlus fire modeling system, version 4.0: User's Guide. USDA, Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR-106WWW, July 2008.
12. Fundamentals of Wildland Fire Fighting, International Fire Service Training Association, Oklahoma State University, Stillwater, OK 3rd ed. 1998.
13. Essentials of Fire Fighting, International Fire Service Training Association, Oklahoma State University, Stillwater, OK 5th ed., 2008.
14. Firefighter's Handbook, Essentials of Firefighting and Emergency Response, 2nd ed. Thomson Delmar Learning, Clifton Park, NY, 2004.
15. Fundamentals of Fire Fighter Skills, Jones and Bartlett Publishers, Sudbury, MA., 2004.
16. Norman, John, "Extreme Wind Driven Fireproof Multiple Dwelling Fires", With New York Firefighters (WNYF), New York, NY, 1st/2007.
17. Tracy, Gerald, "1 Lincoln Plaza, Operations of the First-Arriving Units at a High-Rise Multiple Dwelling Fire", With New York Firefighters (WNYF), New York, NY., 2nd/1997.
18. Daly, James, D., and Healy, George, "Wind-Driven Queens Fire Provokes Several Maydays", With New York Firefighters (WNYF), New York, NY., 3rd/2006.
19. Tracy, Gerald, Personal Communication.

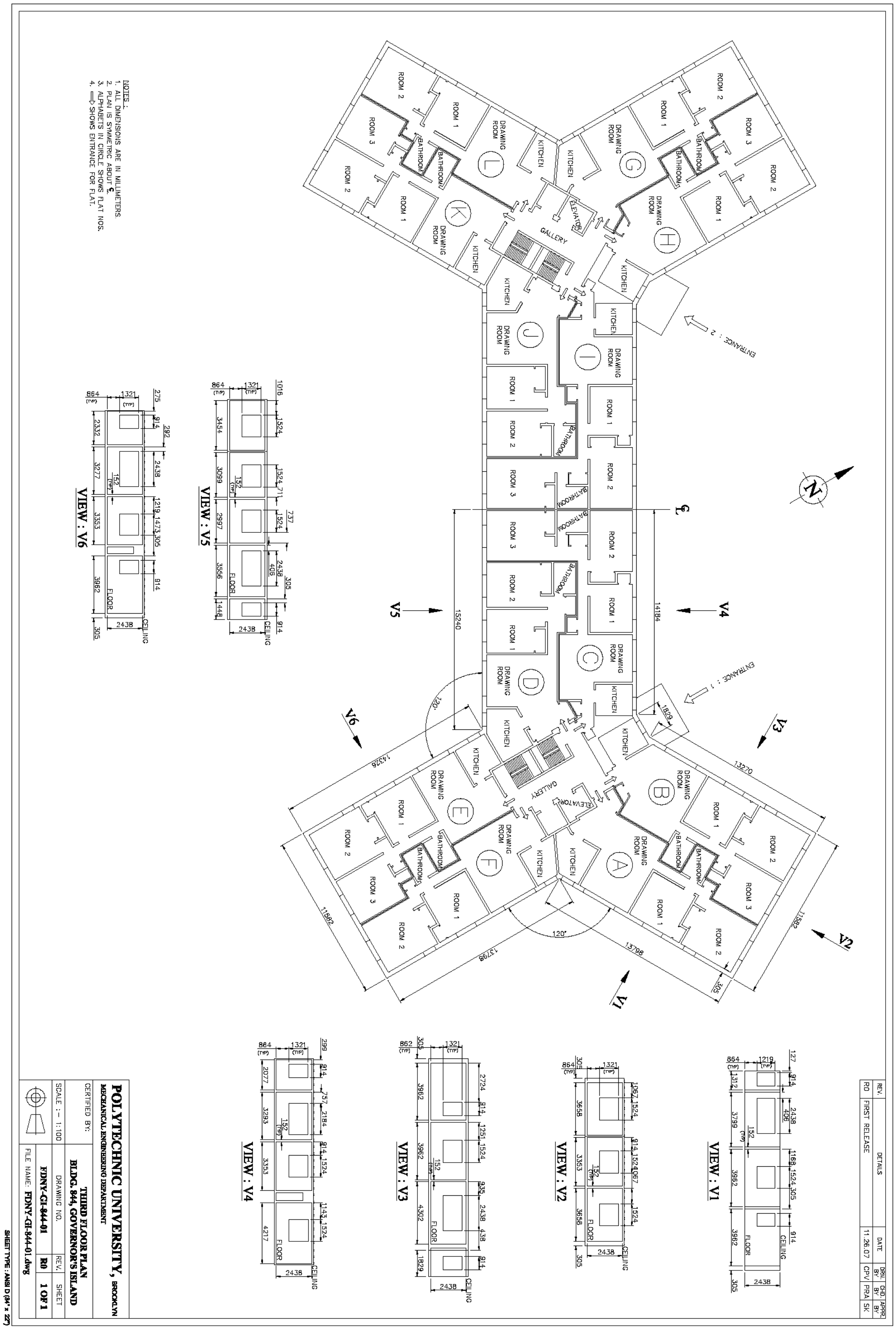
20. Fighting Wind Driven Fires in High Rise Multiple Dwellings, FDNY, 9 Metrotech Center, Brooklyn, NY., 2007.
21. NIOSH F2005-03, Career lieutenant and career fire fighter die and four career fire fighters are seriously injured during a three alarm apartment fire - New York. NIOSH Fire Fighter Fatality Investigation and Prevention Program, Morgantown, WV. Issued January 2006, Revised January 2007.
22. Liu, Henry, "Wind Engineering: A Handbook for Structural Engineers". Prentice Hall, Englewood Cliffs, NJ 1991. pp62-64.
23. Simiu, Emil and Scanlan, Robert H., "Wind Effects on Structures, Fundamentals and Applications to Design", 3rd ed.. John Wiley & Sons, New York, NY, 1996, p 520.
24. *Investigation Number 02-50-10, Captain Jay Jahnke, Houston Fire Department, October 13, 2001* , State Fire Marshal's Office Line of Duty Death Investigation, Texas Department of Insurance, Austin, Texas.
25. NIOSH F98-26, Eight-Alarm Fire in a 27-story High-Rise Apartment Building for the Elderly Nearly Claims the Life of One Fire Fighter – Missouri. NIOSH Fire Fighter Fatality Investigation and Prevention Program, Morgantown, WV. February 23, 1999.
26. NIOSH F2007-12, Career Fire Fighter Dies in Wind Driven Residential Structure Fire – Virginia. NIOSH Fire Fighter Fatality Investigation and Prevention Program, Morgantown, WV. Issued May 2008, Revised June 2008.
27. Goldfeder, W., Front Door Left Open by Occupants Advances Fire Onto Firefighters, Firehouse, Vol. 33, No. 3, Melville, NY., March 2008.
28. "Report # 05-0000531." National Firefighter Near-Miss Reporting System. 18 September 2005. 11 September 2008 <http://www.firefighternearmiss.com/gogglemini/h05-0000531.html>.
29. "Report # 06-0000164." "National Firefighter Near-Miss Reporting System. 15 March 2006. 11 September 2008 <http://www.firefighternearmiss.com/googlemini/h06-0000164.html>.
30. "Report # 06-0000186." National Firefighter Near-Miss Reporting System. 24 March 2006. 11 September 2008 <http://www.firefighternearmiss.com/googlemini/h06-0000186.html>.
31. "Report # 06-0000501." National Firefighter Near-Miss Reporting System. 4 October 2006. 11 September 2008 < http://www.firefighternearmiss.com/googlemini/h06-0000501.html>.
32. "Report # 07-0000805." National Firefighter Near-Miss Reporting System. 19 March 2007. 11 September 2008 <http://www.firefighternearmiss.com/googlemini/h07-0000805.html>.
33. "Report # 07-0000960." National Firefighter Near-Miss Reporting System. 14 June 2007. 11 September 2008 <http://www.firefighternearmiss.com/googlemini/h07-00960.html>.
34. "Report # 08-0000154." National Firefighter Near-Miss Reporting System. 25 March 2008. 11 September 2008 <http://www.firefighternearmiss.com/googlemini/h08-0000154.html>.
35. Kerber, S. and Walton, W. D. "Characterizing Positive Pressure Ventilation Using Computational Fluid Dynamics". National Institute of Standards and Technology, Gaithersburg, MD., NISTIR 7065, 2003.
36. Kerber, S. and Walton, W. D. "Effect of Positive Pressure Ventilation on a Room Fire." National Institute of Standards and Technology, Gaithersburg, MD., NISTIR 7213, 2005.
37. Kerber, S. and Walton, W. D. "Full Scale Evaluation of Positive Pressure Ventilation in a Fire Fighter Training Building." National Institute of Standards and Technology, Gaithersburg, MD., NISTIR 7342, 2006.
38. Kerber, S. "Evaluation of the Ability of Fire Dynamic Simulator to Simulate Positive Pressure Ventilation in the Laboratory and Practical Scenarios." National Institute of Standards and Technology, Gaithersburg, MD., NISTIR 7315, 2006.

39. Kerber, S., Madrzykowski, D., Stroup, D. "Evaluating Positive Pressure Ventilation In Large Structures: High-Rise Pressure Experiments." National Institute of Standards and Technology, Gaithersburg, MD., NISTIR 7412, 2007.
40. Kerber, S., Madrzykowski, D., "Evaluating Positive Pressure Ventilation In Large Structures: High-Rise Fire Experiments." National Institute of Standards and Technology, Gaithersburg, MD., NISTIR 7468, 2007.
41. Taylor, B.N., and Kuyatt, C.E., "Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results", National Institute of Standards and Technology, Gaithersburg. MD., NIST TN 1297, January 1993.
42. Setra Model 264, Very Low Pressure Transducer Data Sheet Rev E., Setra Systems, Boxborough, MA., December 2002.
43. Omega Engineering Inc., The Temperature Handbook, Vol. MM, pages Z-39-40, Stamford, CT., 2004.
44. Blevins, L.G., "Behavior of Bare and Aspirated Thermocouples in Compartment Fires", National Heat Transfer Conference, 33rd Proceedings. HTD99-280. August 15-17, 1999, Albuquerque, NM, 1999.
45. Pitts, W.M., E. Braun, R.D. Peacock, H.E. Mitler, E. L. Johnsson, P.A. Reneke, and L.G.Blevins, "Temperature Uncertainties for Bare-Bead and Aspirated Thermocouple Measurements in Fire Environments," Thermal Measurements: The Foundation of Fire Standards. American Society for Testing and Materials (ASTM). Proceedings. ASTM STP 1427. December 3, 2001, Dallas, TX.
46. Fit 5 Product Information Sheet, ARA Safety Inc., Vancouver BC 2008
47. Abeles, F.J.; Del Vecchio, R.J.; and Himel, V.H., A Firefighter's Integrated Life Protection System: Phase I, Design and Performance Requirements. Grumman Aerospace Corporation, Bethpage, New York, September 1974.
48. Peacock, Richard, D., Krasny, John, F., Rockett, John, A., and Huang, Dingyi, *Protecting Firefighters Exposed in Room Fires, Part 2: Performance of Turnout Coat Materials Under Actual Fire Conditions.* Fire Technology, Vol. 26, No. 3, August 1990, pp 202-222.
49. Donnelly, M.K., Davis, W.D., Lawson, J.R., amd Selepak, M.J., *Thermal Environment for Electronic Equipment Used by First Responders.* National Institute of Standards and Technology, Gaithersburg, MD, NIST TN 1474, January 2006.
50. Madrzykowski, D., *Fatal Training Fires: Fire Analysis for the Fire Service*. Interflam 2007. International Interflam Conference, 11$^{th}$ Proceedings London, England, September 3-5, 2007. Interscience Communications, London, England. pp 1169-1180.
51. Personal communication with Richard Edgeworth, Director of Training, Chicago Fire Department, March 18, 2009.

# 9 Appendices

## 9.1 Appendix A – Detailed Drawings

Polytechnic University and the Bureau of Alcohol Tobacco Firearms and Explosives (ATF) measured the structure and their detailed drawings are included in this appendix.


NOTES :
1. ALL DIMENSIONS ARE IN MILLIMETERS
2. PLAN IS SYMMETRIC ABOUT ℄
3. ALPHABETS IN CIRCLE SHOWS FLAT NOS.
4. ⟹ SHOWS ENTRANCE FOR FLAT.
VIEW : V1
VIEW : V2
VIEW : V3
VIEW : V4
VIEW : V5
VIEW : V6
ENTRANCE : 1
ENTRANCE : 2
GALLERY
ELEVATOR
POLYTECHNIC UNIVERSITY, BROOKLYN
MECHANICAL ENGINEERING DEPARTMENT
CERTIFIED BY:
THIRD FLOOR PLAN
BLDG. 844, GOVERNOR'S ISLAND
SCALE : 1:100
DRAWING NO.
FDNY-GI-844-01
REV.
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SHEET
1 OF 1
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SHEET TYPE : ANSI D (34" x 22")
REV.
DETAILS
DATE
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FIRST RELEASE
11.26.07

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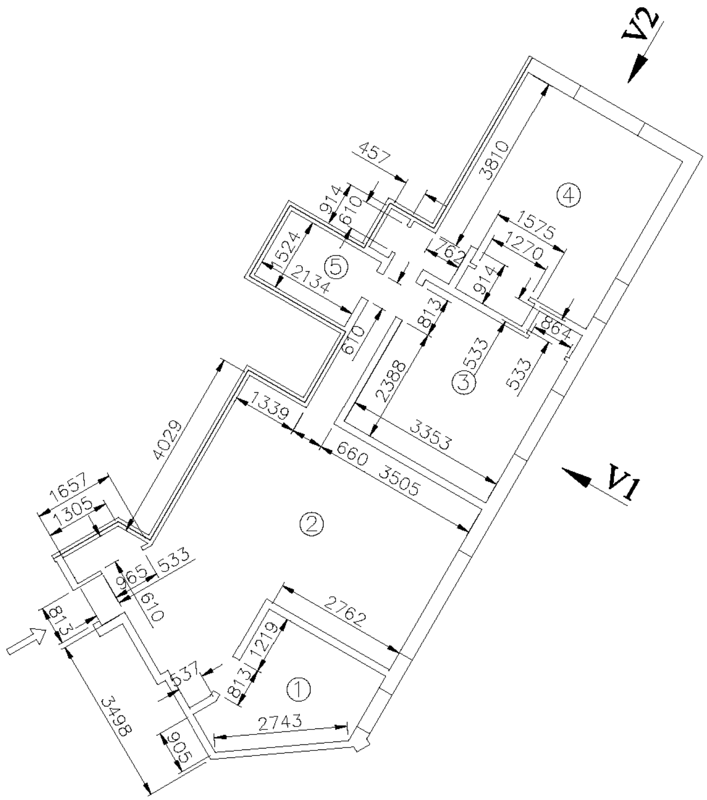
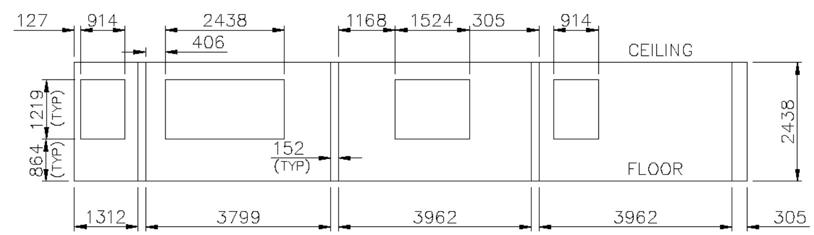
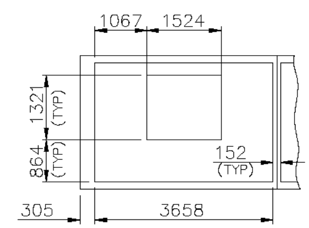



## VIEW : V1

| SR. | DESCRIPTION |
|---|---|
| 1 | KITCHEN |
| 2 | DRAWING ROOM |
| 3 | ROOM 1 |
| 4 | ROOM 2 |
| 5 | BATHROOM |




## VIEW : V2

NOTES :

1. ALL DIMENSIONS ARE IN MILLIMETERS.
2. ALL INTERNAL WALL THK ARE 152 MILLIMETERS EXCEPT CLOSET DOORS.
3. ⇨ SHOWS ENTRANCE FOR FLAT.
4. ALL DIMENSIONS ARE APPROXIMATE.

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SCALE **1:80**

DWG. NO. **FDNY-GI-844-02**

REV. **R0**

SHEET **1 OF 1**

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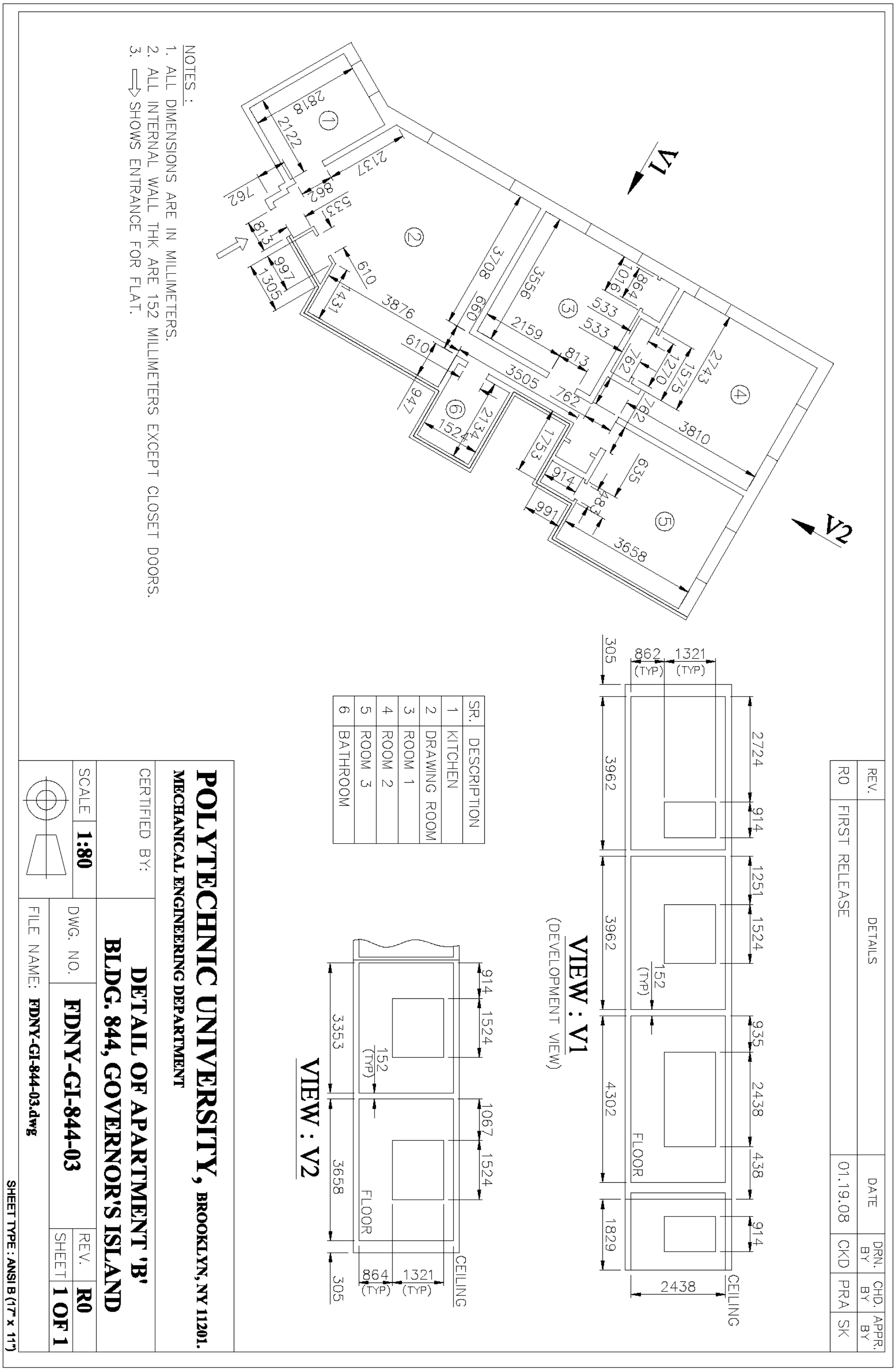
NOTES :
1. ALL DIMENSIONS ARE IN MILLIMETERS.
2. ALL INTERNAL WALL THK ARE 152 MILLIMETERS EXCEPT CLOSET DOORS.
3. ⇨ SHOWS ENTRANCE FOR FLAT.
V1
V2
VIEW : V1
(DEVELOPMENT VIEW)
VIEW : V2
FLOOR
CEILING
SR. DESCRIPTION
1 KITCHEN
2 DRAWING ROOM
3 ROOM 1
4 ROOM 2
5 ROOM 3
6 BATHROOM
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MECHANICAL ENGINEERING DEPARTMENT
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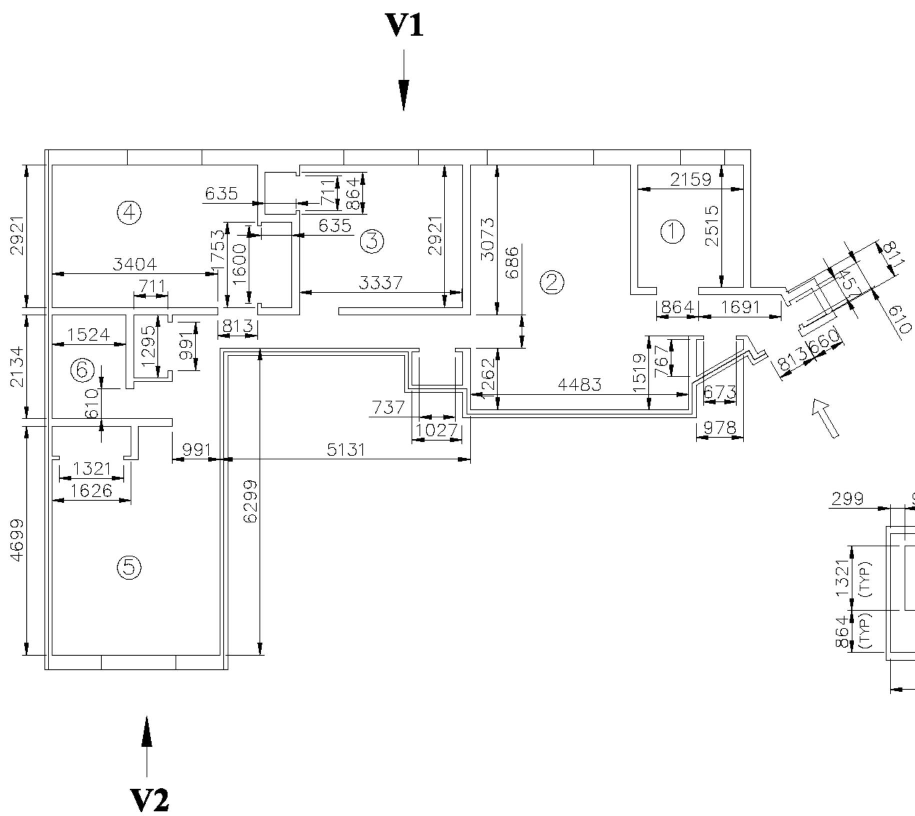


| SR. | DESCRIPTION |
|---|---|
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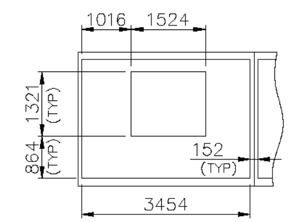
| 2 | DRAWING ROOM |
| 3 | ROOM 1 |
| 4 | ROOM 2 |
| 5 | ROOM 3 |
| 6 | BATHROOM |

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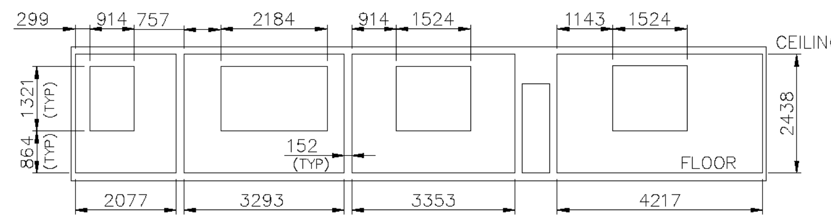


VIEW : V1

NOTES :

1. ALL DIMENSIONS ARE IN MILLIMETERS.
2. ALL INTERNAL WALL THK ARE 152 MILLIMETERS EXCEPT CLOSET DOORS.
3. ⇨ SHOWS ENTRANCE FOR FLAT.

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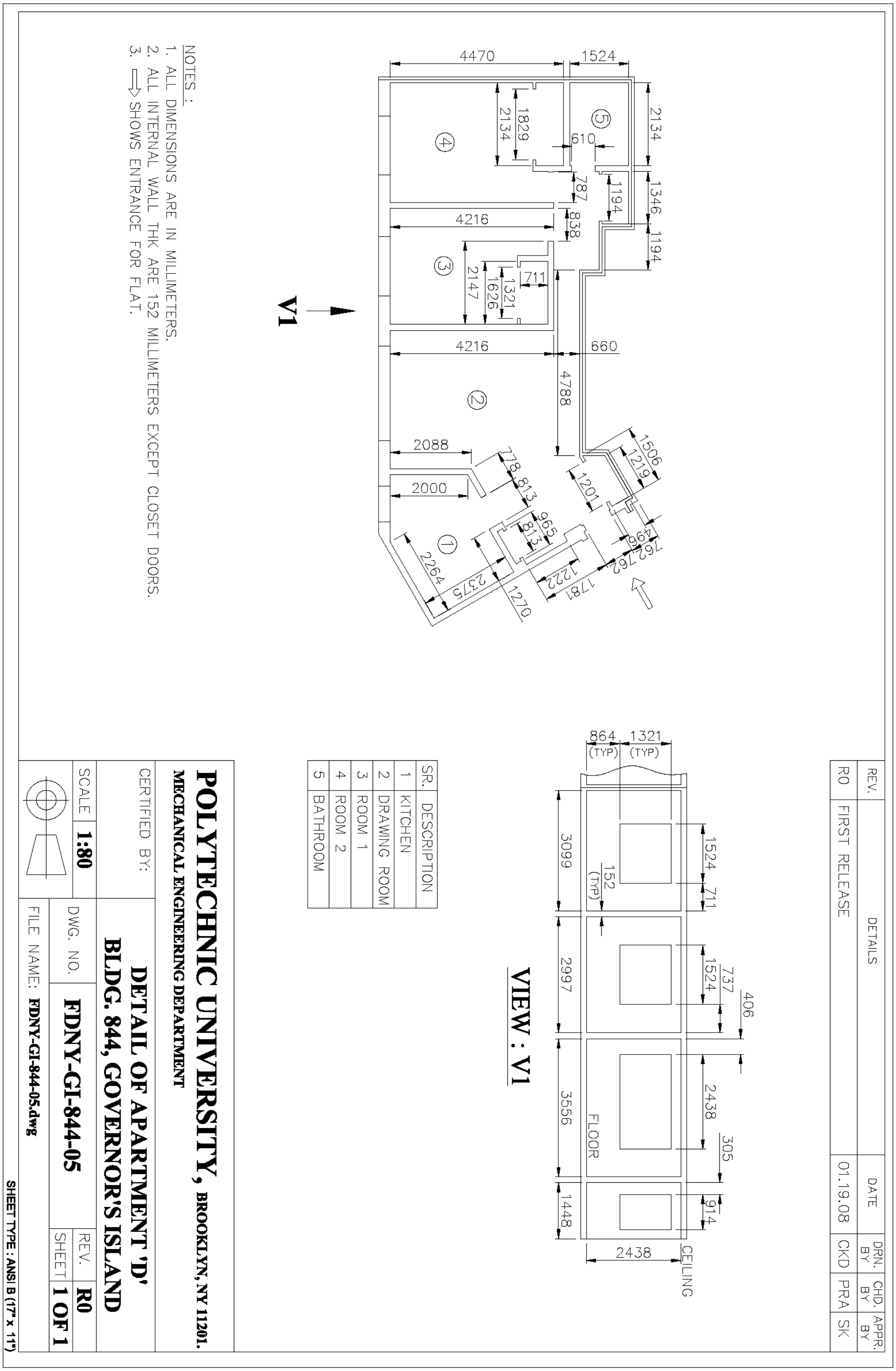
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2. ALL INTERNAL WALL THK ARE 152 MILLIMETERS EXCEPT CLOSET DOORS.
3. SHOWS ENTRANCE FOR FLAT.
V1
VIEW : V1
FLOOR
CEILING
SR. DESCRIPTION
1 KITCHEN
2 DRAWING ROOM
3 ROOM 1
4 ROOM 2
5 BATHROOM
REV. DETAILS DATE DRN. BY CHD. BY APPR. BY
R0 FIRST RELEASE 01.19.08 CKD PRA SK
POLYTECHNIC UNIVERSITY, BROOKLYN, NY 11201.
MECHANICAL ENGINEERING DEPARTMENT
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BLDG. 844, GOVERNOR'S ISLAND
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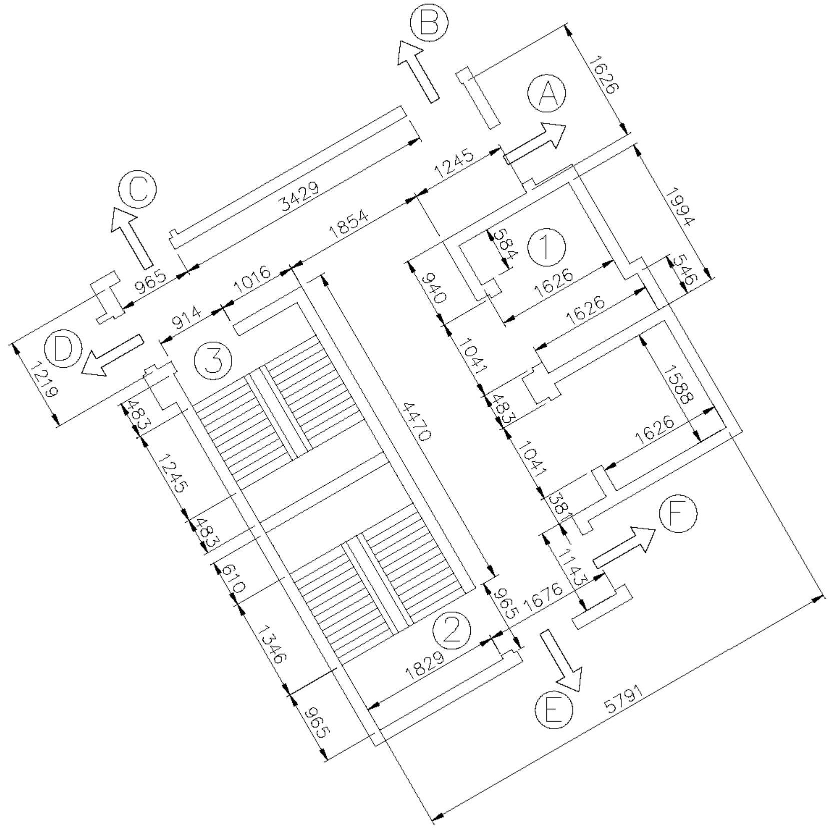


| SR. | DESCRIPTION |
|---|---|
| 1 | ELEVATOR |
| 2 | STAIRCASE 1 |
| 3 | STAIRCASE 2 |

NOTES :

1. ALL DIMENSIONS ARE IN MILLIMETERS.
2. ALL INTERNAL WALL THK ARE 152 MILLIMETERS EXCEPT CLOSET DOORS.
3. ⟹ SHOWS ENTRANCE FOR FLAT.

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**MECHANICAL ENGINEERING DEPARTMENT**

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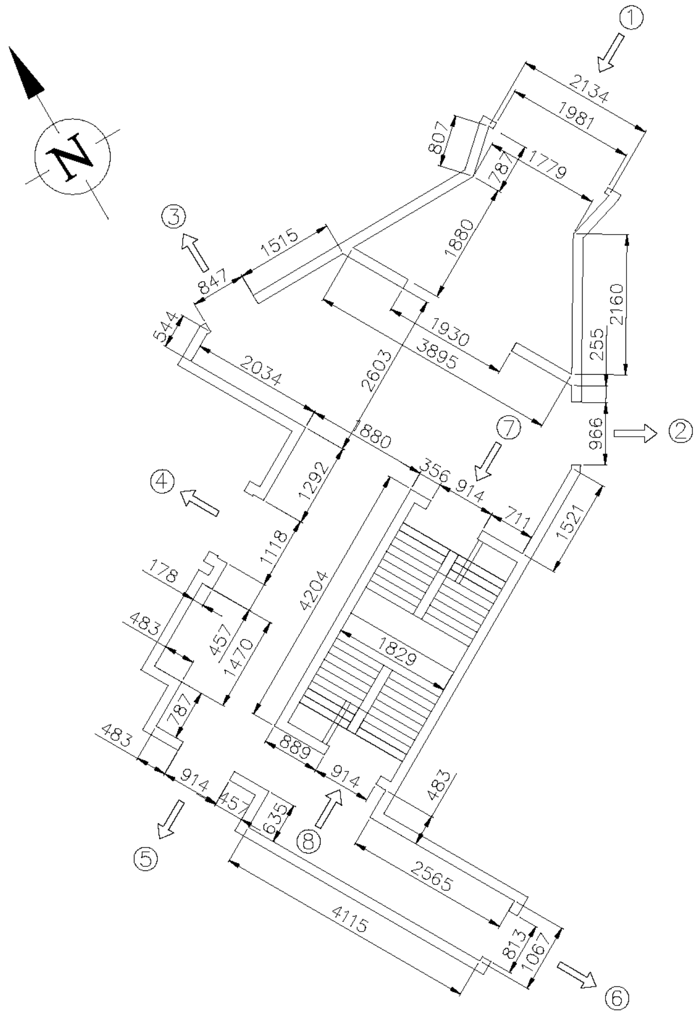


| SR. | DESCRIPTION |
|---|---|
| 1 | ENTRANCE FOR APTS# G-J. |
| 2 | APT# 1-I. |
| 3 | LAUNDRY |
| 4 | ELEVATOR |
| 5 | APT# 1-H. |
| 6 | EMERGENCY EXIT |
| 7 | STAIRCASE 1 |
| 8 | STAIRCASE 2 |

NOTES :

1. ALL DIMENSIONS ARE IN MILLIMETERS.

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CERTIFIED BY:

**FIRST FLOOR GALLERY PLAN (APT# G-J)**
**BLDG. 844, GOVERNOR'S ISLAND**

SCALE **1:60**

DWG. NO. **FDNY-GI-844-07**

REV. **R0**

SHEET **1 OF 1**

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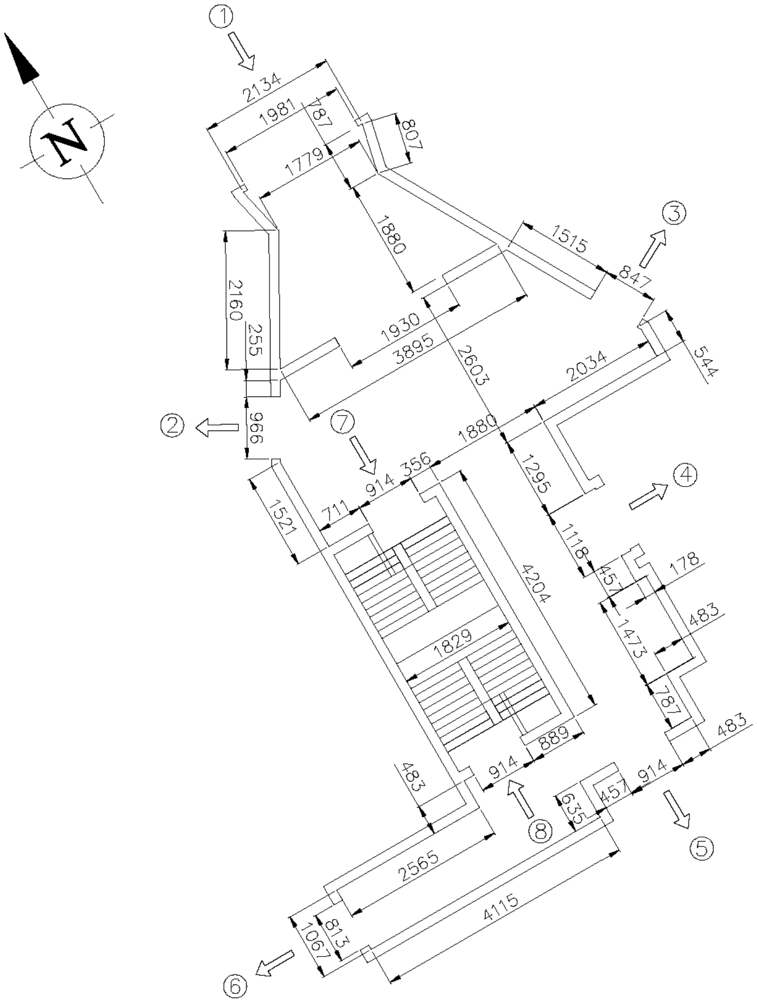


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| R0 | FIRST RELEASE | 01.25.07 | CKD | PRA | SK |

| SR. | DESCRIPTION |
|---|---|
| 1 | ENTRANCE FOR APTS# A–F. |
| 2 | APT# 1–C. |
| 3 | LAUNDRY |
| 4 | ELEVATOR |
| 5 | APT# 1–B. |
| 6 | EMERGENCY EXIT |
| 7 | STAIRCASE 1 |
| 8 | STAIRCASE 2 |

NOTES :

1. ALL DIMENSIONS ARE IN MILLIMETERS.

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| CERTIFIED BY: | **FIRST FLOOR GALLERY PLAN (APT# A-F) BLDG. 844, GOVERNOR'S ISLAND** | | | | |
| SCALE | **1:60** | DWG. NO. | **FDNY-GI-844-08** | REV. | **R0** |
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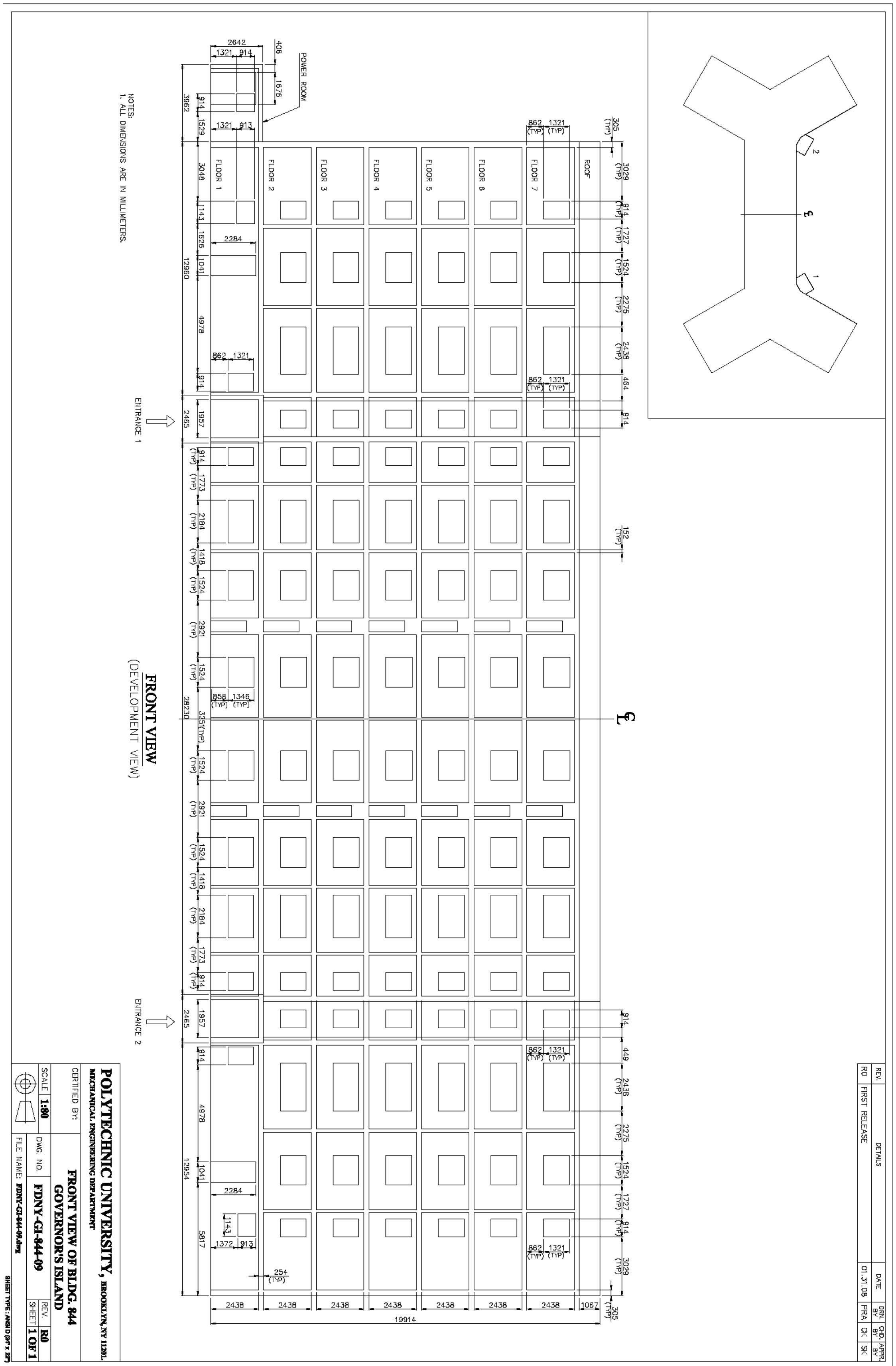

FRONT VIEW
(DEVELOPMENT VIEW)
NOTES:
1. ALL DIMENSIONS ARE IN MILLIMETERS.
POWER ROOM
ENTRANCE 1
ENTRANCE 2
FLOOR 1
FLOOR 2
FLOOR 3
FLOOR 4
FLOOR 5
FLOOR 6
FLOOR 7
ROOF
POLYTECHNIC UNIVERSITY, BROOKLYN, NY 11201.
MECHANICAL ENGINEERING DEPARTMENT
CERTIFIED BY:
FRONT VIEW OF BLDG. 844
GOVERNOR'S ISLAND
SCALE 1:80
DWG. NO. FDNY-GI-844-09
REV. R0
SHEET 1 OF 1
REV. DETAILS DATE
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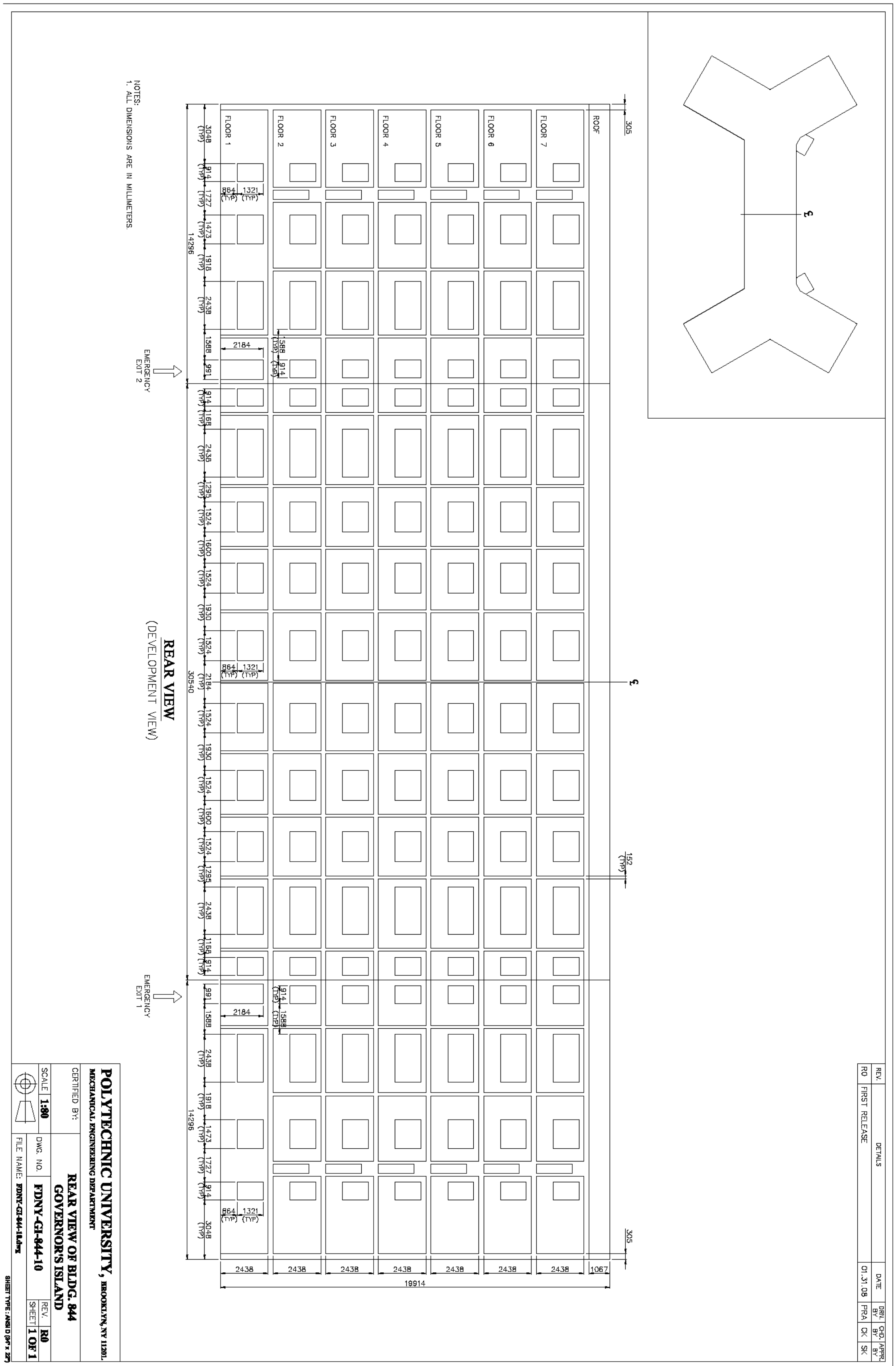
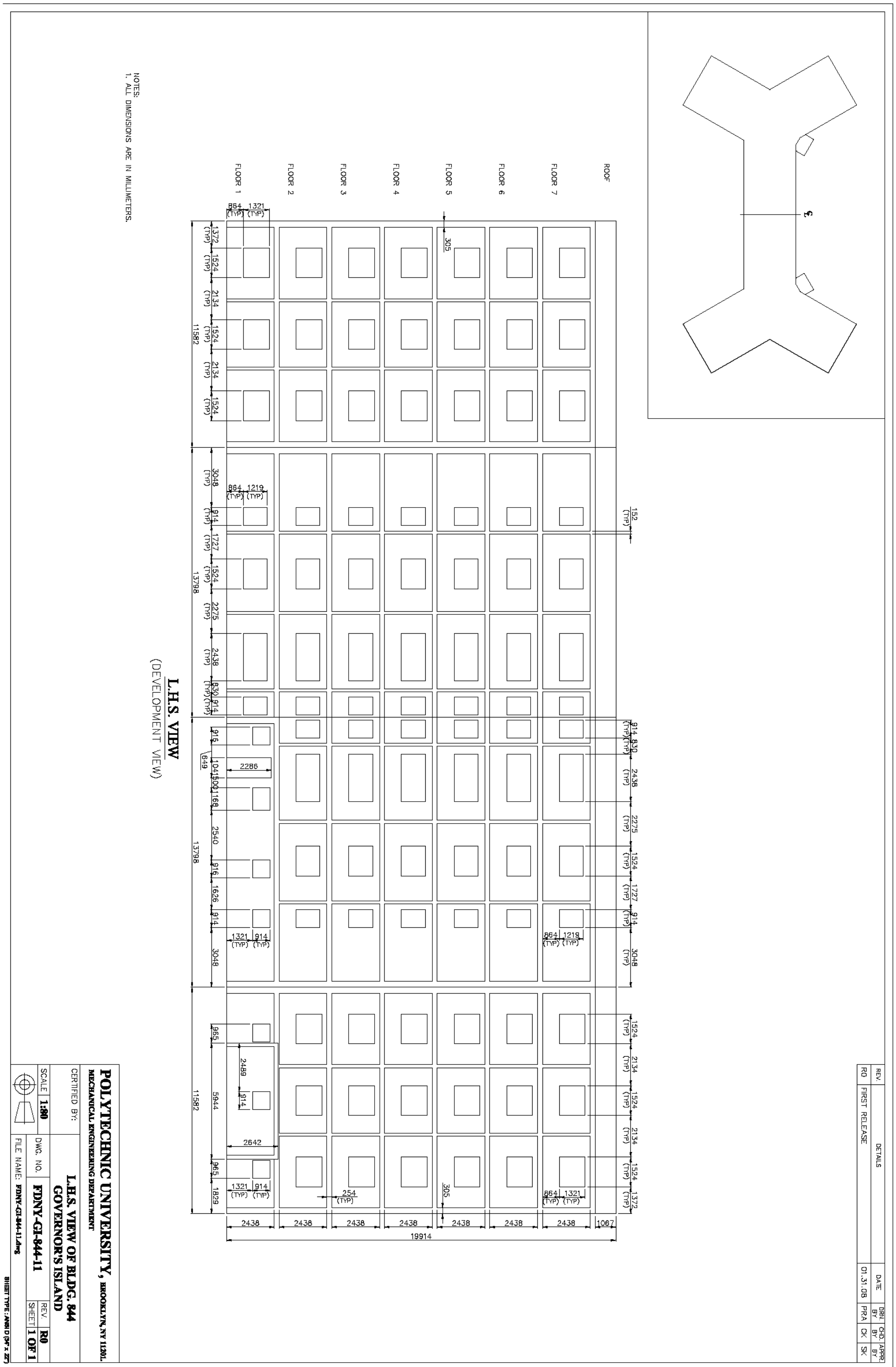

NOTES:
1. ALL DIMENSIONS ARE IN MILLIMETERS
FLOOR 1
FLOOR 2
FLOOR 3
FLOOR 4
FLOOR 5
FLOOR 6
FLOOR 7
ROOF
EMERGENCY EXIT 2
EMERGENCY EXIT 1
REAR VIEW
(DEVELOPMENT VIEW)
14296
30540
19914
REV.
DETAILS
DATE
DRN. BY
CHD. BY
APPR. BY
R0
FIRST RELEASE
01.31.08
PRA
CK
SK
POLYTECHNIC UNIVERSITY, BROOKLYN, NY 11201.
MECHANICAL ENGINEERING DEPARTMENT
CERTIFIED BY:
REAR VIEW OF BLDG. 844
GOVERNOR'S ISLAND
SCALE
1:80
DWG. NO.
FDNY-GI-844-10
REV.
R0
SHEET
1 OF 1
FILE NAME: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ROOF
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FLOOR 6
FLOOR 5
FLOOR 4
FLOOR 3
FLOOR 2
FLOOR 1
L.H.S. VIEW
(DEVELOPMENT VIEW)
11582
13798
13798
11582
19914
REV. DETAILS DATE DRN BY CHD. BY APPR. BY
R0 FIRST RELEASE 01.31.08 PRA CK SK
POLYTECHNIC UNIVERSITY, BROOKLYN, NY 11201.
MECHANICAL ENGINEERING DEPARTMENT
CERTIFIED BY:
L.H.S. VIEW OF BLDG. 844
GOVERNOR'S ISLAND
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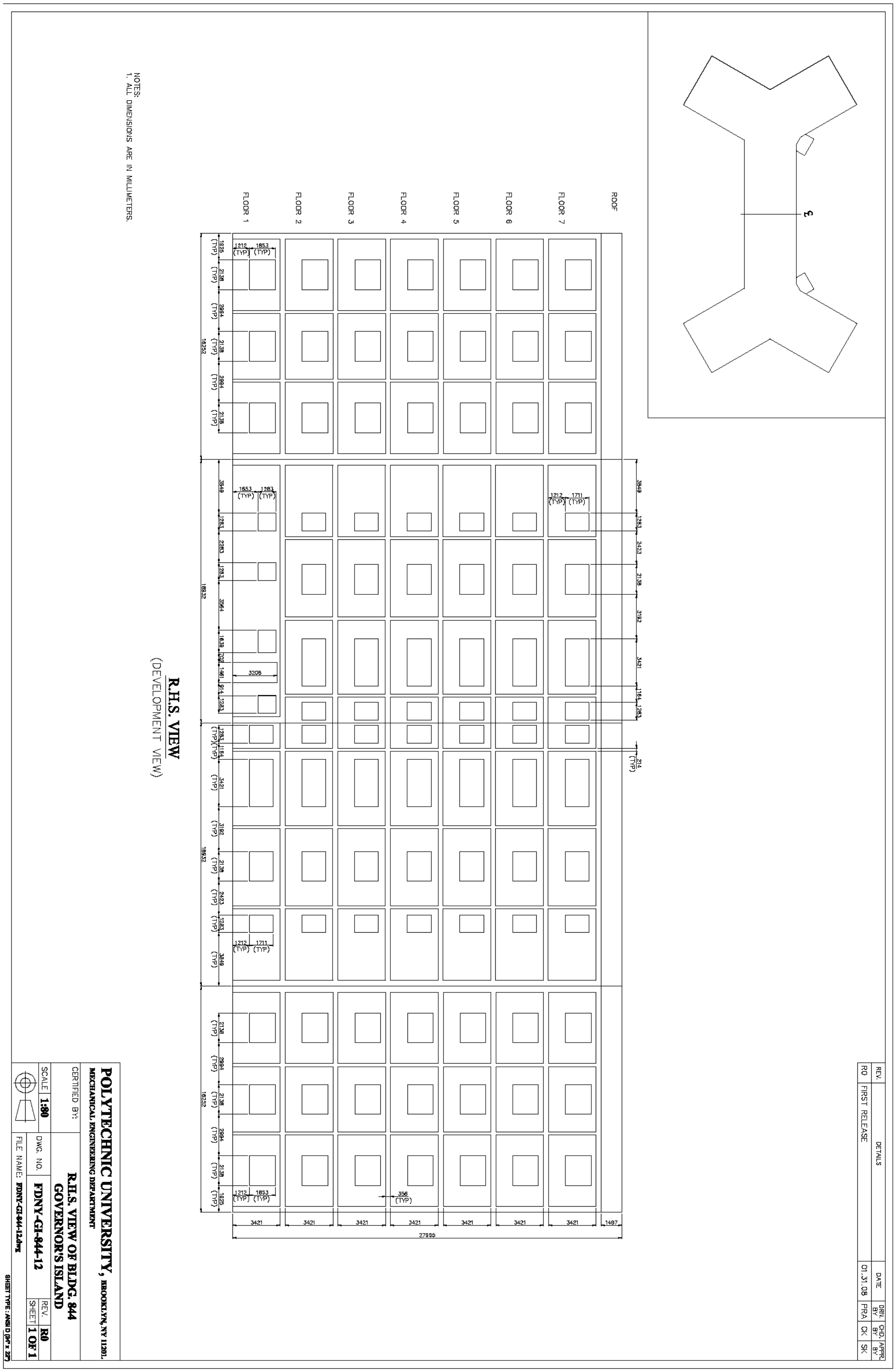
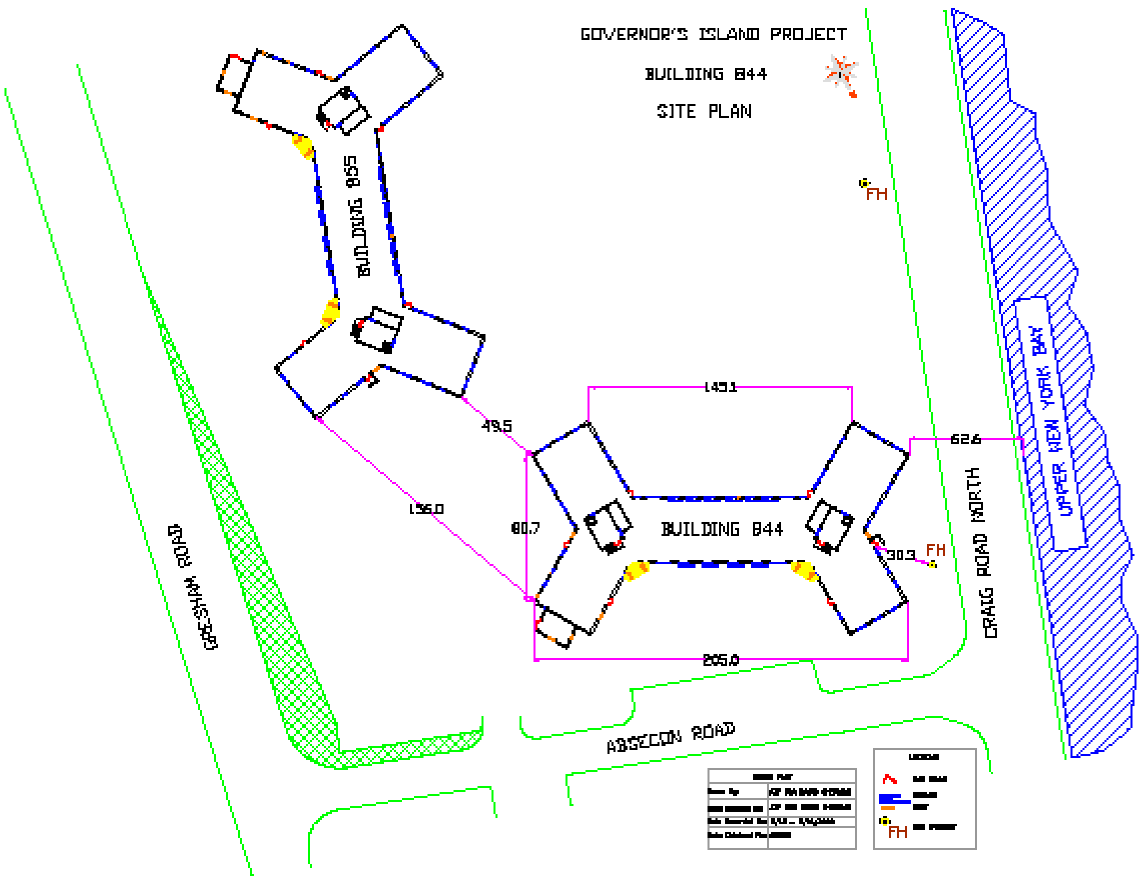
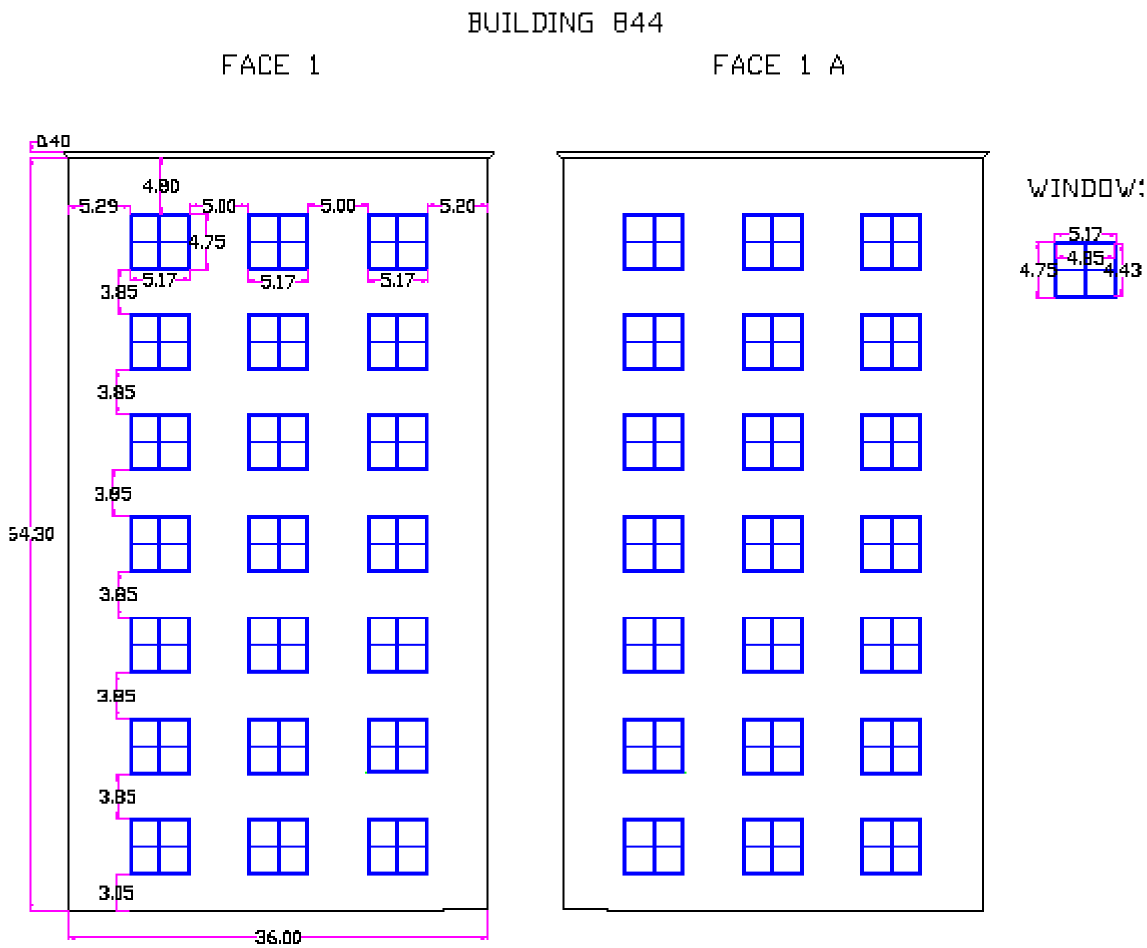
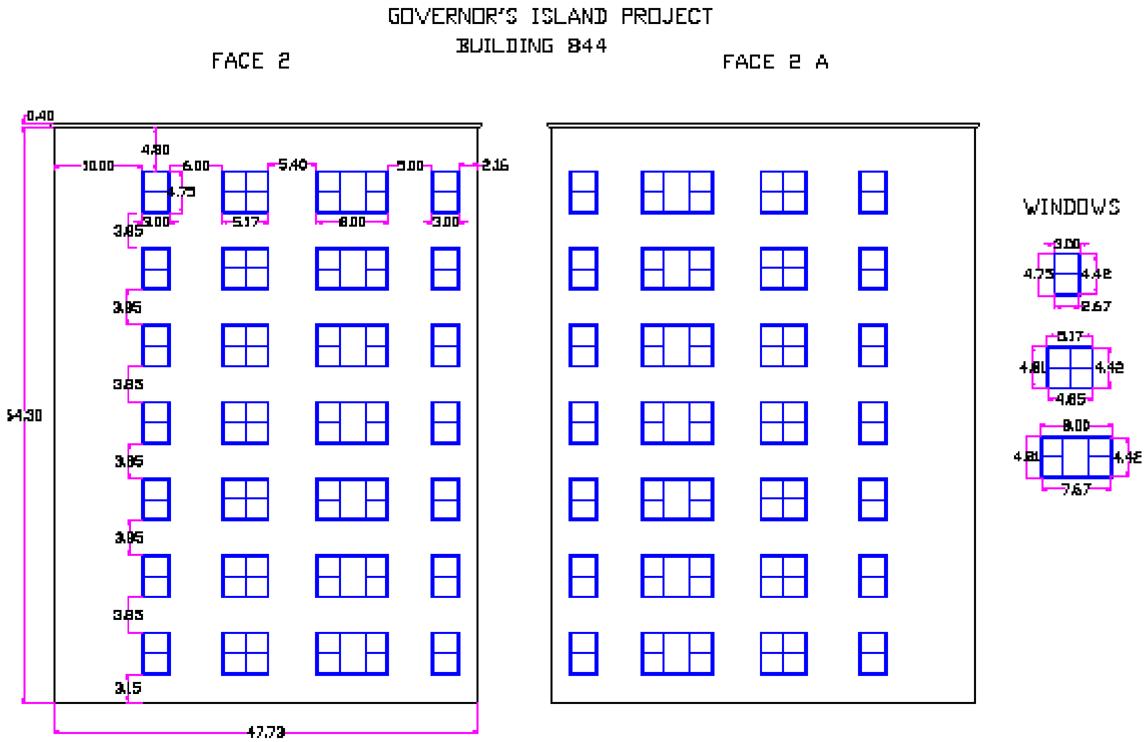

NOTES:
1. ALL DIMENSIONS ARE IN MILLIMETERS.
FLOOR 1
FLOOR 2
FLOOR 3
FLOOR 4
FLOOR 5
FLOOR 6
FLOOR 7
ROOF
R.H.S. VIEW
(DEVELOPMENT VIEW)
REV.
DETAILS
DATE
DRN. BY
CHD. BY
APPR. BY
R0
FIRST RELEASE
01.31.08
PRA
CK
SK
POLYTECHNIC UNIVERSITY, BROOKLYN, NY 11201.
MECHANICAL ENGINEERING DEPARTMENT
CERTIFIED BY:
R.H.S. VIEW OF BLDG. 844
GOVERNOR'S ISLAND
SCALE 1:80
DWG. NO. FDNY-GI-844-12
REV. R0
SHEET 1 OF 1
FILE NAME: FDNY-GI-844-12.dwg
SHEET TYPE : ANSI D (34" x 22")
27955
3421
1497

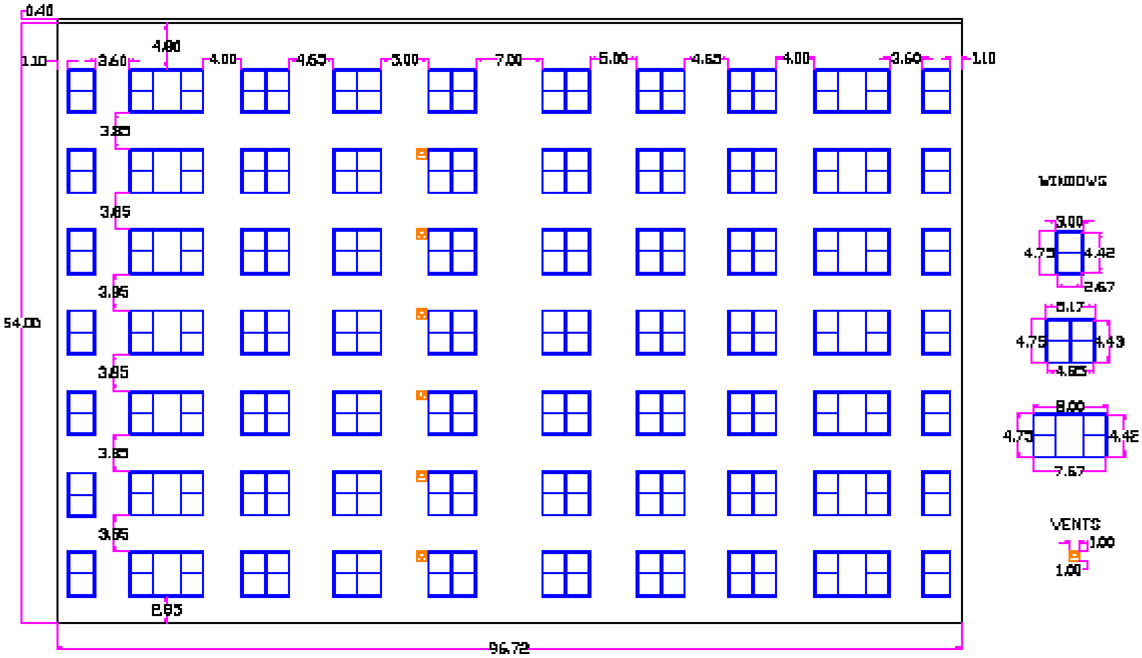

GOVERNOR'S ISLAND PROJECT
BUILDING 844
SITE PLAN
FH
BUILDING 855
145.1
49.5
62.6
156.0
80.7
BUILDING 844
30.3
FH
205.0
GRESHAM ROAD
CRAIG ROAD NORTH
UPPER NEW YORK BAY
ABSECON ROAD

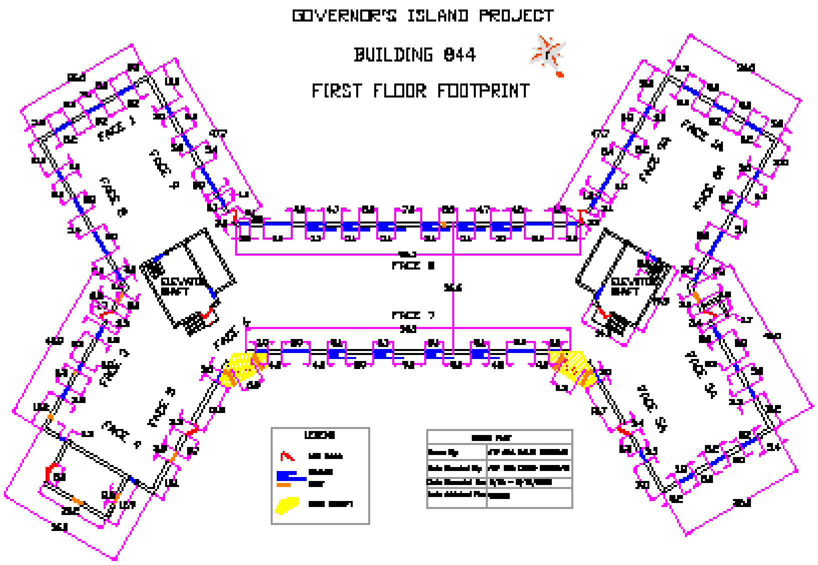

BUILDING 844
FACE 1
FACE 1 A
WINDOWS
0.40
4.90
5.29
5.00
5.00
5.20
4.75
5.17
5.17
5.17
3.85
3.85
3.85
3.85
3.85
3.85
3.05
54.30
36.00
5.17
4.85
4.75
4.43

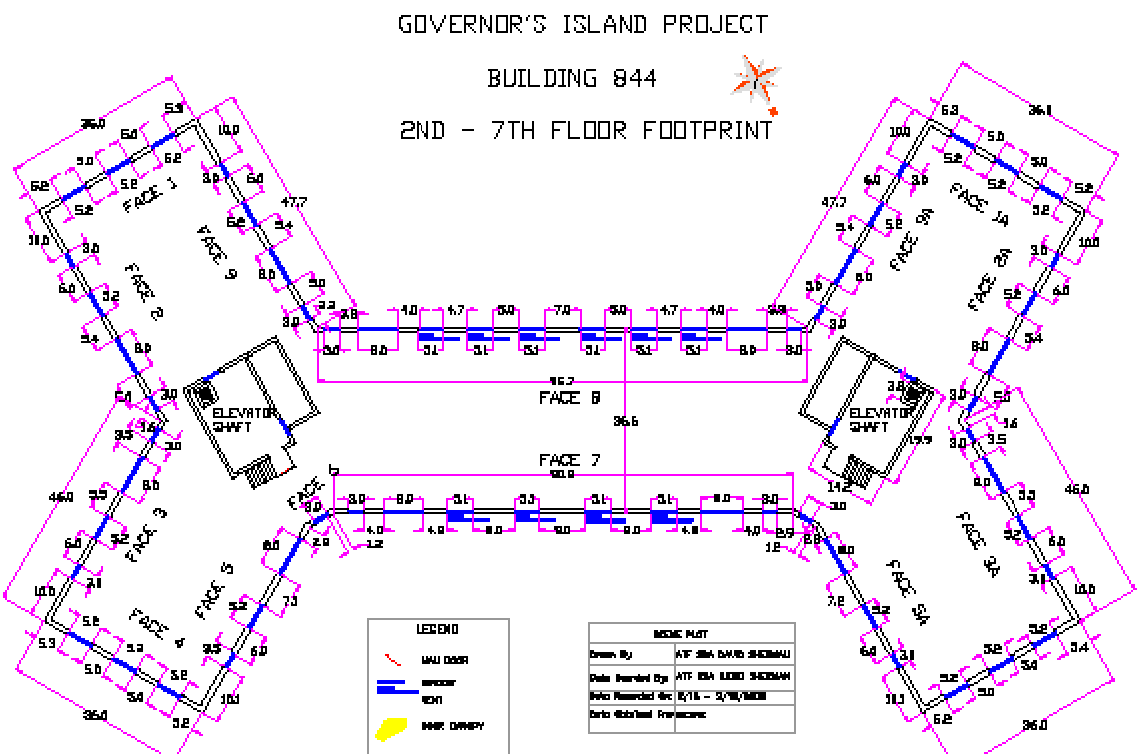

GOVERNOR'S ISLAND PROJECT
BUILDING 844
FACE 2
FACE 2 A
WINDOWS
0.40
4.80
10.00
6.00
5.40
5.00
2.16
4.75
3.00
5.17
8.00
3.00
3.85
54.30
3.15
47.73
4.42
2.67
4.85
7.67

GOVERNOR'S ISLAND PROJECT
BUILDING 844

FACE 8




GOVERNOR'S ISLAND PROJECT
BUILDING 844
FIRST FLOOR FOOTPRINT
ELEVATOR SHAFT
FACE 8
FACE 7
LEGEND


GOVERNOR'S ISLAND PROJECT
BUILDING 844
2ND - 7TH FLOOR FOOTPRINT
FACE 1
FACE 2
FACE 3
FACE 4
FACE 5
FACE 6
FACE 7
FACE 8
FACE 9
FACE 1A
FACE 2A
FACE 3A
FACE 5A
FACE 9A
ELEVATOR SHAFT
ELEVATOR SHAFT
LEGEND

## 9.2 Appendix B – Fuel Distribution

**Table 9.2-1. Fuel Distribution for the A Apartments**

| | Apartment 3A | | Apartment 5A | | Apartment 7A | |
|---|---|---|---|---|---|---|
| Item | Bedroom | Living Room | Bedroom | Living Room | Bedroom | Living Room |
| Mattress | 1 | | 1 | | 1 | |
| Box Spring | 1 | | 1 | | 1 | |
| Head Board | 1 | | 1 | | 1 | |
| Bedding/Pillows | 1 | | 1 | | 1 | |
| Upholstered Chair (Brown) | | 1 | | 1 | | 1 |
| Upholstered Chair (Red) | 1 | | 1 | | 1 | |
| Chair (Red w/ wood arms) | | 1 | | 1 | | 1 |
| Desk Chair (Green) | | 2 | | 1 | | 1 |
| Desk Chair (Brown) | 1 | | 1 | | 1 | |
| Coffee Table | | 1 | | 1 | | 1 |
| Desk (Dark Brown w/ blue top) | | 1 | | 1 | | 1 |
| Desk (Light Brown) | 1 | 1 | 1 | 1 | 1 | 1 |
| Dresser (Dark Brown) | 1 | | 1 | | 1 | |
| Dresser (Light Brown) | | 1 | | 1 | | 1 |
| Table Lamp | 2 | 2 | 2 | 2 | 2 | 2 |
| Nightstand (Light Brown) | 1 | 1 | | 2 | | 2 |
| Nightstand (Dark Brown) | | 1 | 1 | | 1 | |
| Round Table | | 1 | | 1 | | 1 |
| Sofa | | 1 | | 1 | | 1 |
| Floor Lamp | | 1 | | 1 | | 1 |
| TV (Small) | 1 | | | | | |
| TV (Large) | | | 1 | 1 | 1 | 1 |

**Table 9.2-2. Fuel Distribution for the E Apartments**

| | Apartment 3E | | Apartment 5E | | Apartment 7E | |
|---|---|---|---|---|---|---|
| Item | Bedroom | Living Room | Bedroom | Living Room | Bedroom | Living Room |
| Mattress | 1 | | 1 | | 1 | |
| Box Spring | 1 | | 1 | | 1 | |
| Head Board | 1 | | 1 | | 1 | |
| Bedding/Pillows | 1 | | 1 | | 1 | |
| Upholstered Chair (Brown) | | | | | | 1 |
| Upholstered Chair (Red) | 1 | | 1 | | 1 | |
| Chair (Red w/ wood arms) | | 1 | | 1 | | 1 |
| Desk Chair (Green) | | 2 | | 1 | | 1 |
| Desk Chair (Brown) | 1 | | 1 | | 1 | |
| Coffee Table | | 1 | | 1 | | 1 |
| Desk (Dark Brown w/ blue top) | | 1 | | 1 | | 1 |
| Desk (Light Brown) | 1 | 1 | 1 | 1 | 1 | 1 |
| Dresser (Dark Brown) | 1 | | 1 | | 1 | |
| Dresser (Light Brown) | | 1 | | 1 | | 1 |
| Table Lamp | 2 | 2 | 2 | 2 | 2 | 2 |
| Nightstand (Light Brown) | | 2 | | 2 | | 2 |
| Nightstand (Dark Brown) | 1 | | 1 | | 1 | |
| Round Table | | 1 | | 1 | | 1 |
| Sofa | | 2 | | 2 | | 2 |
| Floor Lamp | | 1 | | 1 | | 1 |
| TV (Small) | 1 | | | | | |
| TV (Large) | | 1 | 1 | 1 | 1 | 1 |

**Table 9.2-3. Fuel distribution for the G Apartments**

| Item | Apartment 3G | | Apartment 5G | | Apartment 7G | |
|---|---|---|---|---|---|---|
| | Bedrooms | Living Room | Bedrooms | Living Room | Bedrooms | Living Room |
| Mattress | 2 | | 2 | | 2 | |
| Box Spring | 2 | | 2 | | 2 | |
| Head Board | 2 | | 2 | | 2 | |
| Bedding/Pillows | 2 | | 2 | | 2 | |
| Upholstered Chair (Brown) | | 1 | | | | 1 |
| Upholstered Chair (Red) | 2 | | 2 | | 2 | |
| Chair (Red w/ wood arms) | | 1 | | 1 | | 1 |
| Desk Chair (Green) | | 2 | | 2 | | 2 |
| Desk Chair (Brown) | 1 | | 1 | | 2 | |
| Coffee Table | | 1 | | 1 | | 1 |
| Desk (Dark Brown w/ blue top) | | 2 | | 2 | | 2 |
| Desk (Light Brown) | 2 | | 2 | | 2 | |
| Dresser (Dark Brown) | 2 | | 2 | | 2 | |
| Dresser (Light Brown) | | 1 | | 1 | | 1 |
| Table Lamp | 2 | 2 | 3 | 2 | 3 | 2 |
| Nightstand (Light Brown) | | 2 | | 2 | | 2 |
| Nightstand (Dark Brown) | 2 | | 2 | | 2 | |
| Round Table | | 2 | | 2 | | 2 |
| Sofa | | 1 | | 1 | | 1 |
| Floor Lamp | | 1 | | 1 | | 1 |
| TV (Small) | 1 | 1 | | | | |
| TV (Large) | | | 1 | 1 | 1 | 1 |

**Table 9.2-4. Fuel distribution for the K Apartments**

| | Apartment 3K | | Apartment 5K | | Apartment 7K | |
|---|---|---|---|---|---|---|
| Item | Bedrooms | Living Room | Bedrooms | Living Room | Bedrooms | Living Room |
| Mattress | 2 | | 2 | | 2 | |
| Box Spring | 2 | | 2 | | 2 | |
| Head Board | 2 | | 2 | | 2 | |
| Bedding/Pillows | 2 | | 2 | | 2 | |
| Upholstered Chair (Brown) | | | | 1 | | 1 |
| Upholstered Chair (Red) | 2 | | 2 | | 2 | |
| Chair (Red w/ wood arms) | | 1 | | 1 | | 1 |
| Desk Chair (Green) | | 1 | | 2 | | 2 |
| Desk Chair (Brown) | | | 1 | | 1 | |
| Coffee Table | | 1 | | 1 | | 1 |
| Desk (Dark Brown w/ blue top) | | 2 | | 2 | | 2 |
| Desk (Light Brown) | 2 | | 2 | | 2 | |
| Dresser (Dark Brown) | 2 | | 2 | | 2 | |
| Dresser (Light Brown) | | 1 | | 1 | | 1 |
| Table Lamp | 3 | 2 | 1 | 2 | 3 | 3 |
| Nightstand (Light Brown) | | 2 | | 2 | | 2 |
| Nightstand (Dark Brown) | 2 | | 2 | | 2 | |
| Round Table | | 2 | | 2 | | 2 |
| Sofa | | 2 | | 2 | | 2 |
| Floor Lamp | | 1 | | 1 | | 1 |
| TV (Small) | 1 | 1 | | | | |
| TV (Large) | | | 1 | 1 | 2 | 1 |

## 9.3 Appendix C – Wind Measurements and Descriptions

Polytechnic University positioned weather stations around the structure to measure wind speed and direction. This appendix includes their data and supporting documentation.

### February 23, 2008

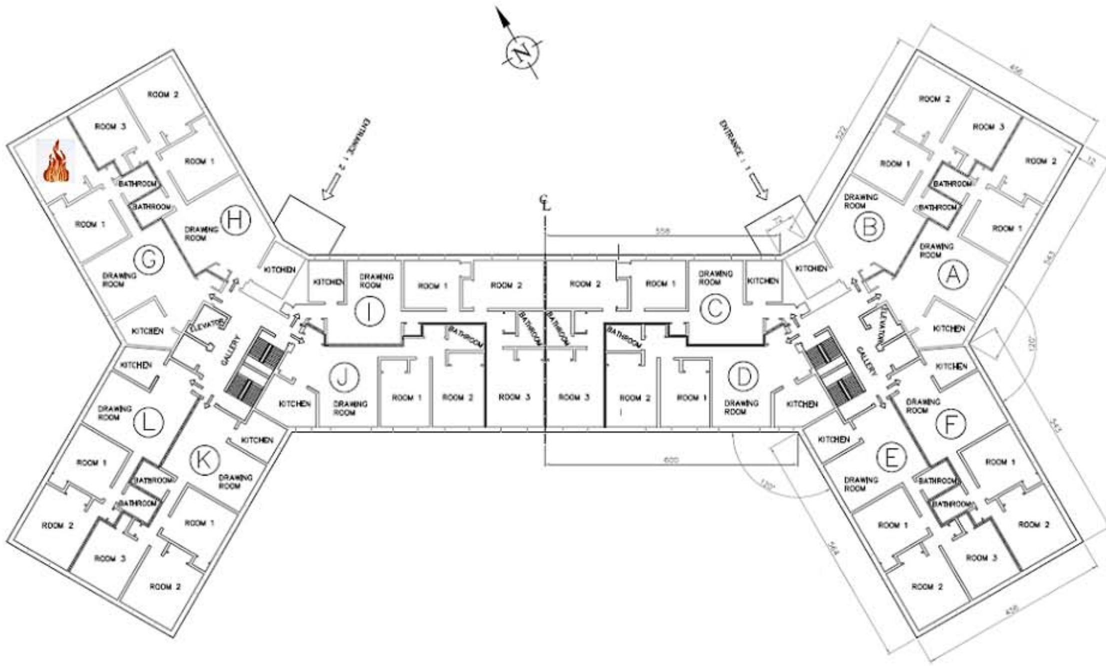
- Two burn tests were executed in apt # 7G.
- First burn test was conducted in bedroom of apt # 7G and second burn test was conducted in living room of apt # 7G.
- In all, six weather stations were located at different position around the building # 844 and measuring wind speed and wind directions at respective locations.
- Weather station 1 and weather station 2 were located on the roof of building and measuring external weather conditions
- Weather station 3 and weather station 4 were located along the wall of building # 844 and measuring the wind speed in vertical plane along the wall.

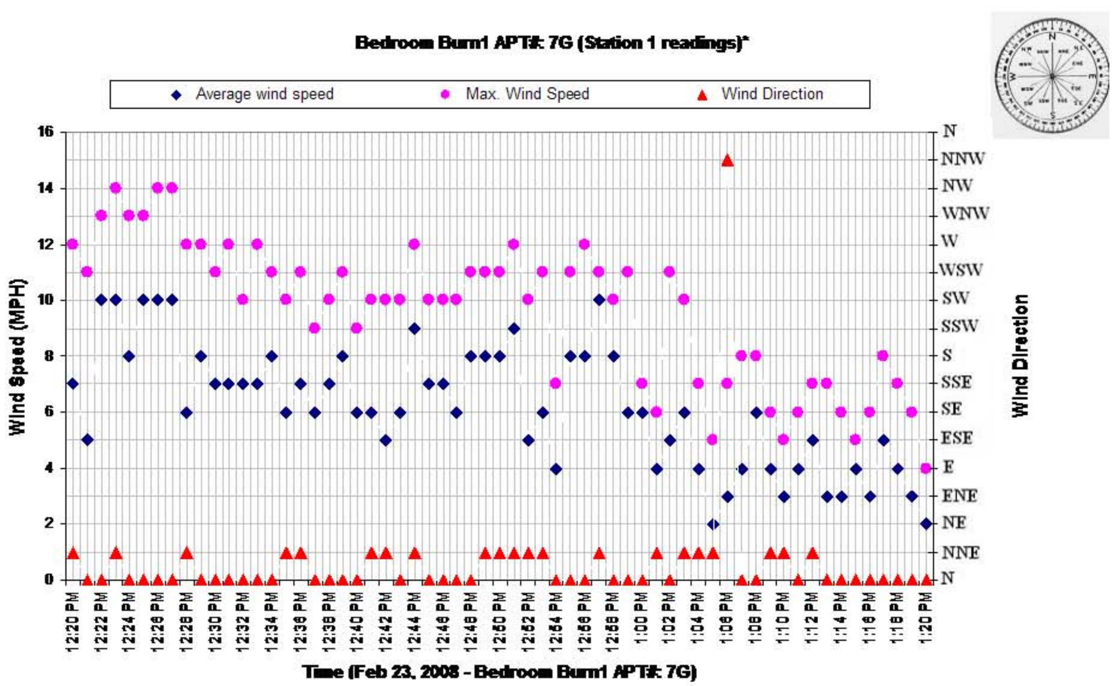
### February 23, 2008

- Weather station 5 and weather station 6 were located on the ground and measuring wind speed in front of the building and on the back side of the building respectively.
- Readings taken for wind speed, wind direction from respective weather stations for every minute during the period of test have been plotted in following graphs:
- Please note that the specific locations of every weather station has been mentioned at the bottom of respective graph.

# February 23, 2008

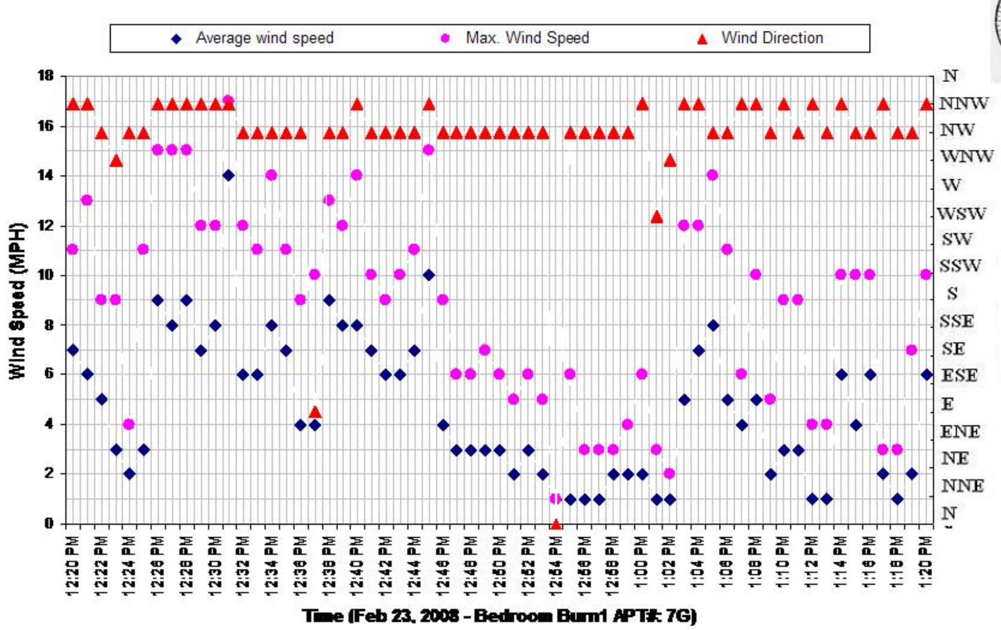
## First burn in bedroom of apt # 7G





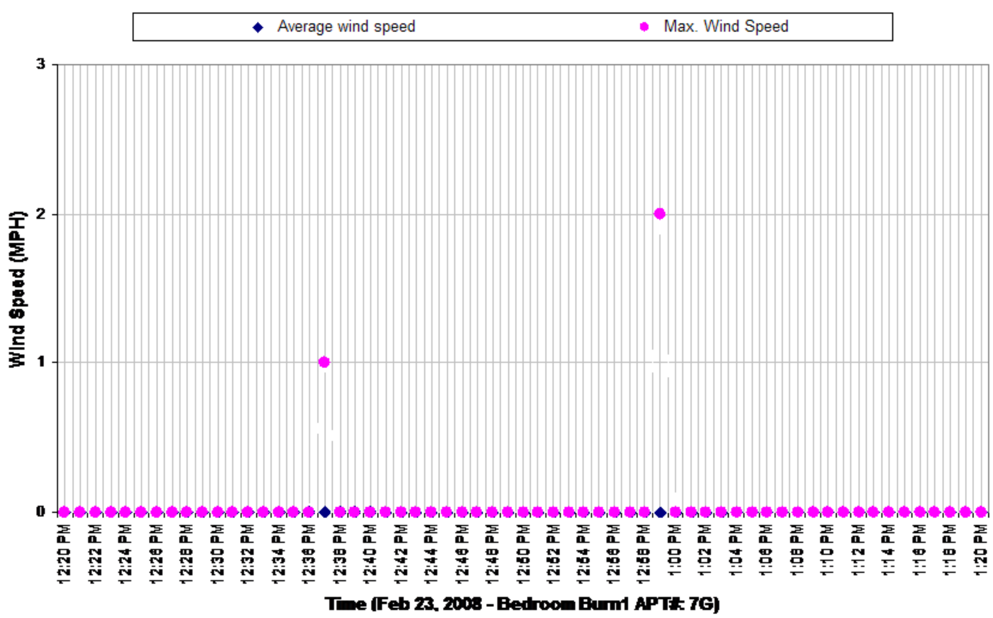

* Station 1 was located on the roof of building #844 : A – F wing

**Bedroom Burn1 APT#: 7G (Station 2 readings)***

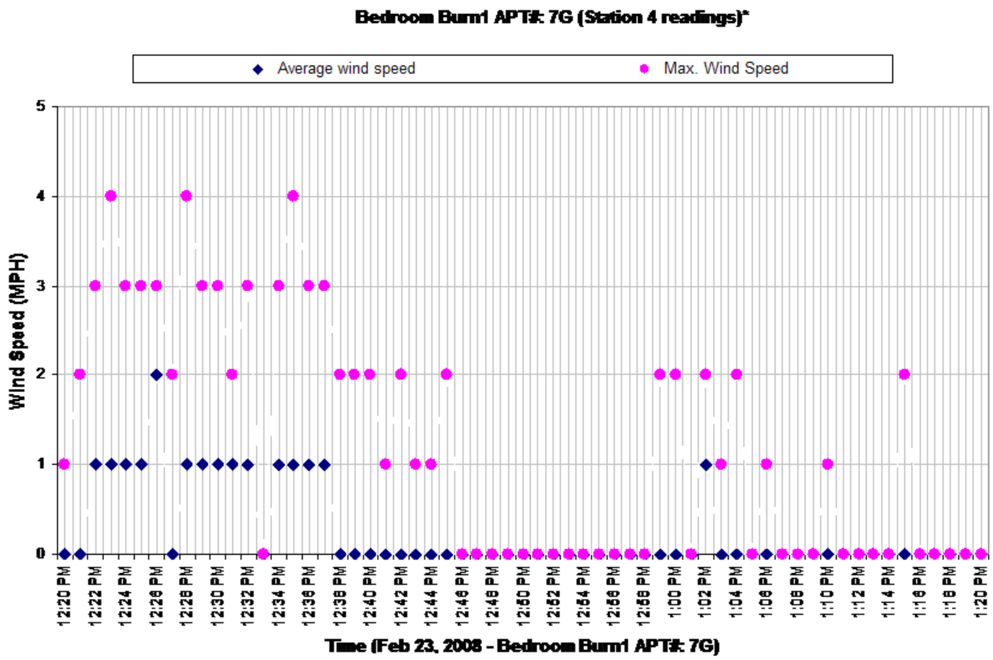



* Station 2 was located on the roof of building #844 : G – L wing

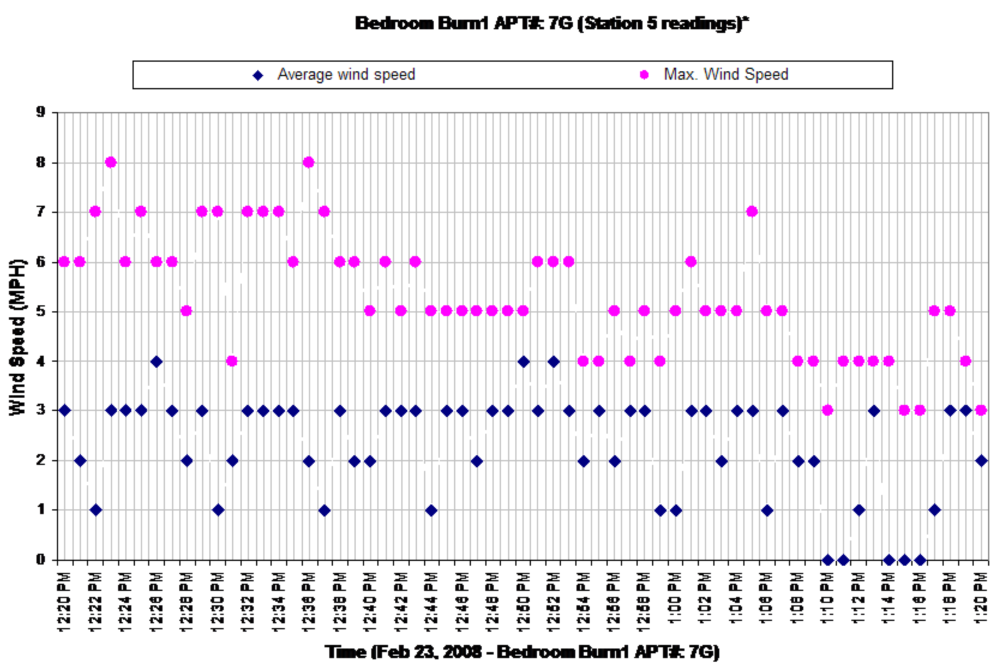
**Bedroom Burn1 APT#: 7G (Station 3 readings)***



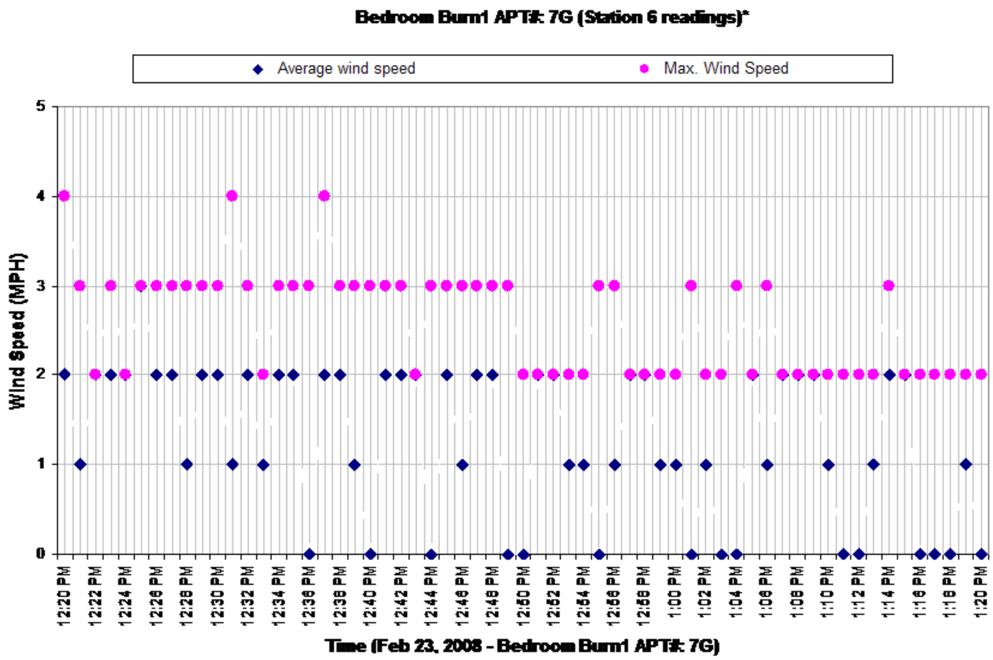

* Station 3 was located on the corner bedroom window along shorter side of apt #: 5G




* Station 4 was located on the living room window along longer side of apt#: 5G



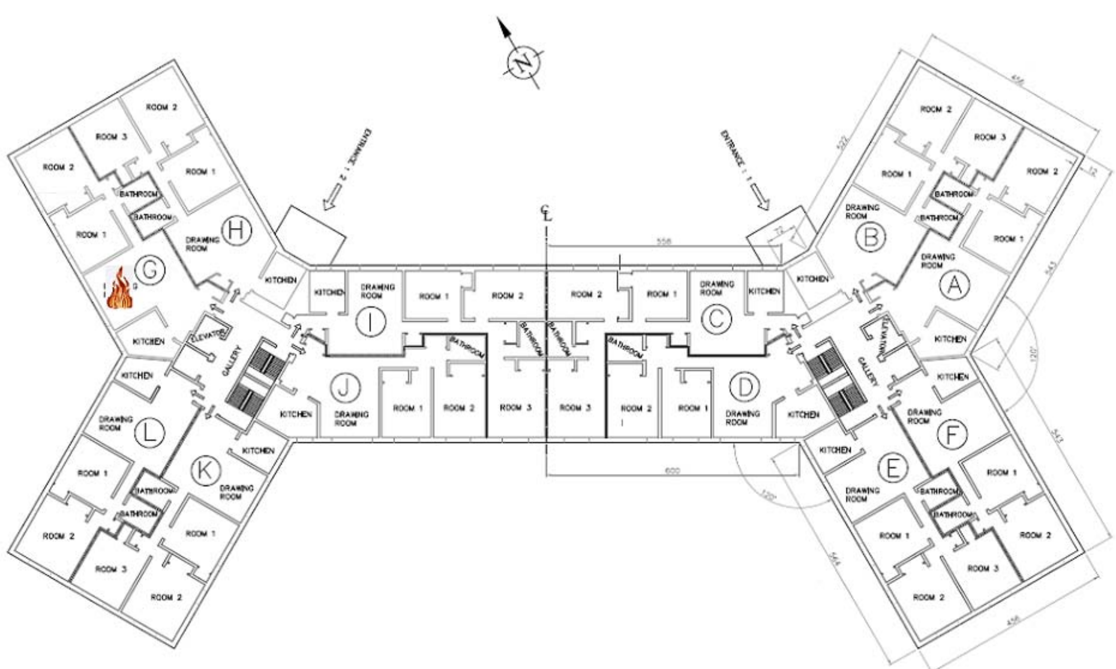

*Station 5 was located on the ground in front of building #844

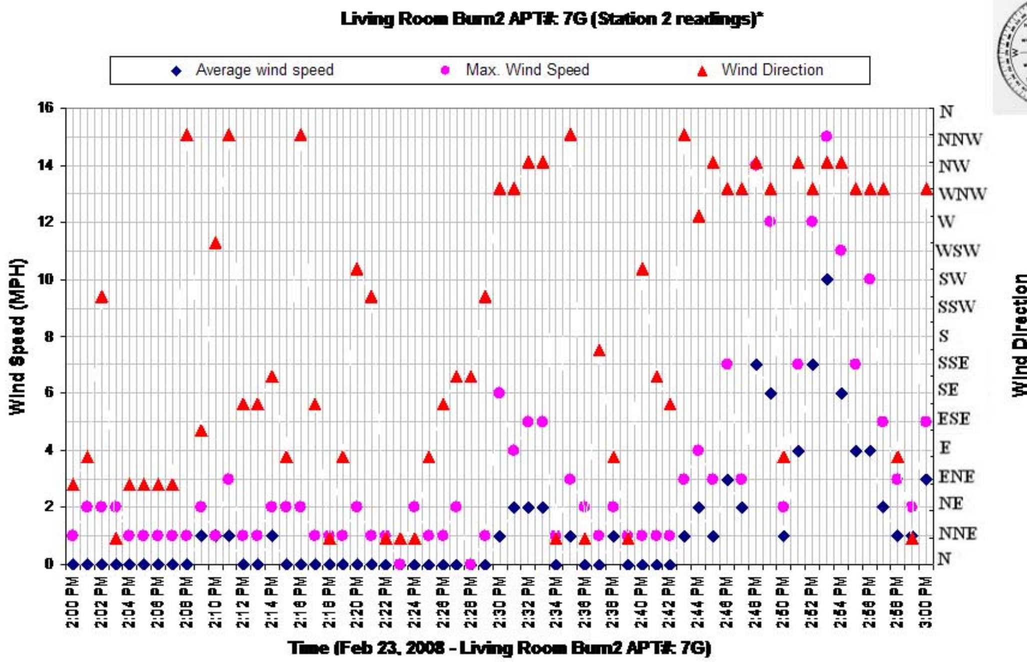


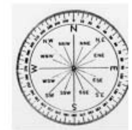

* Station 6 was located on the ground at back side of building #844

# February 23, 2008

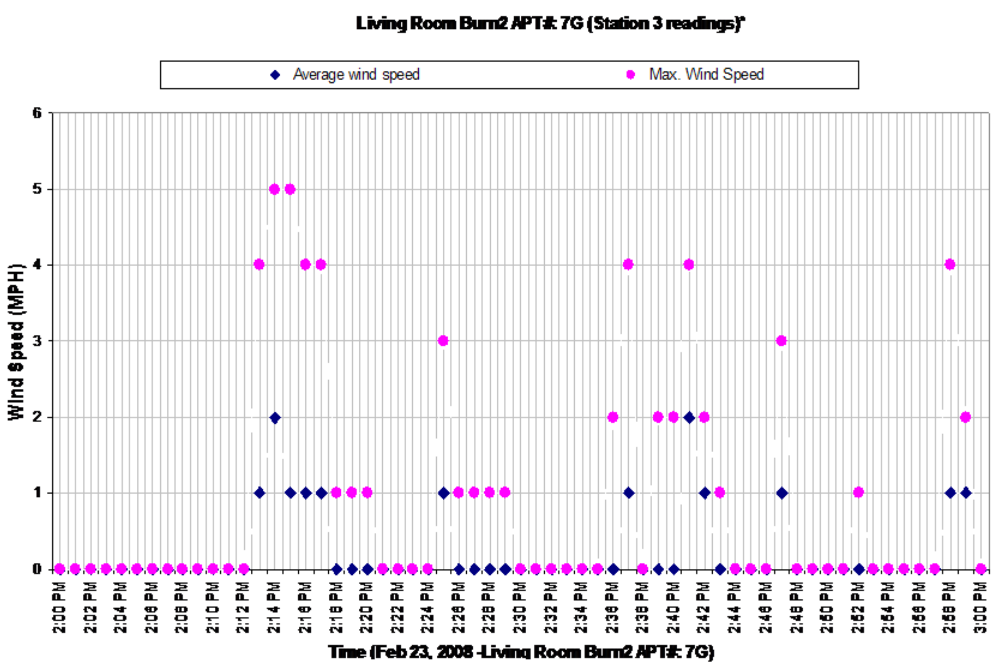
## Second burn in living room of apt # 7G



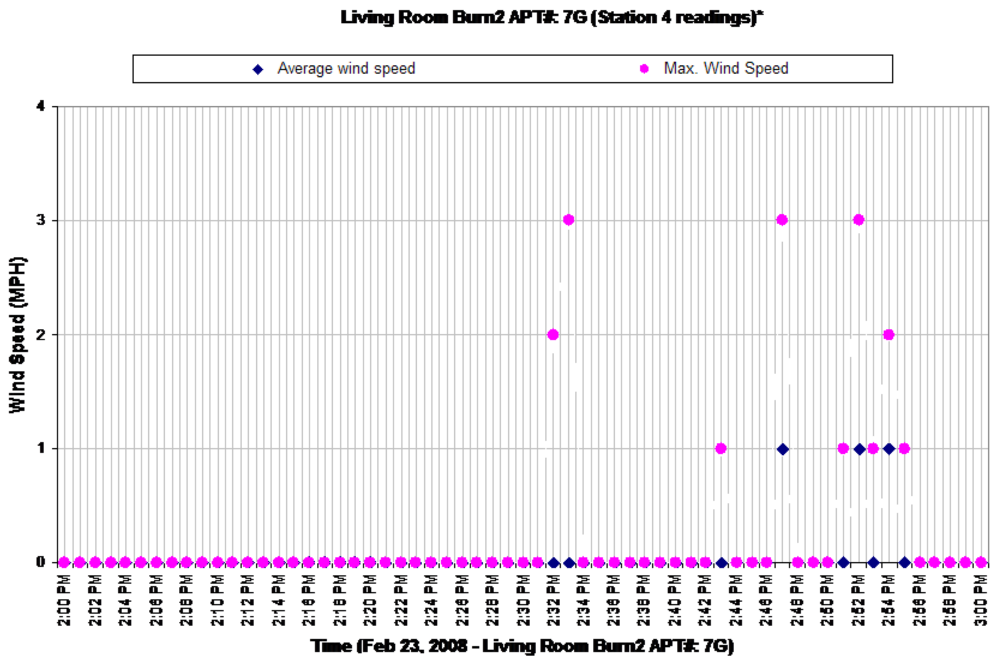


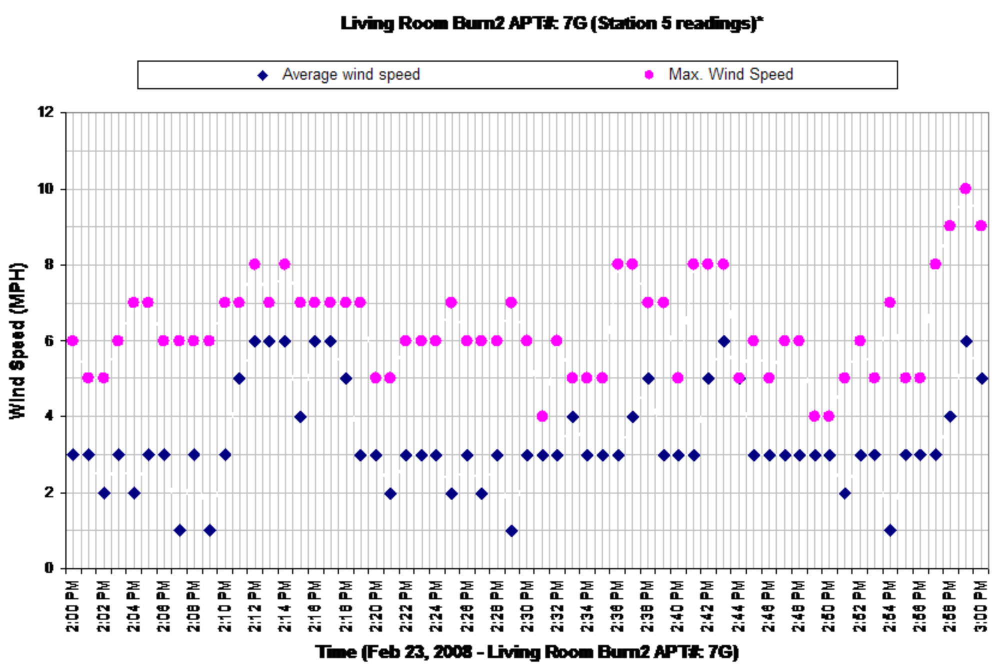
* Station 2 was located on the roof of building #844 : G – L wing



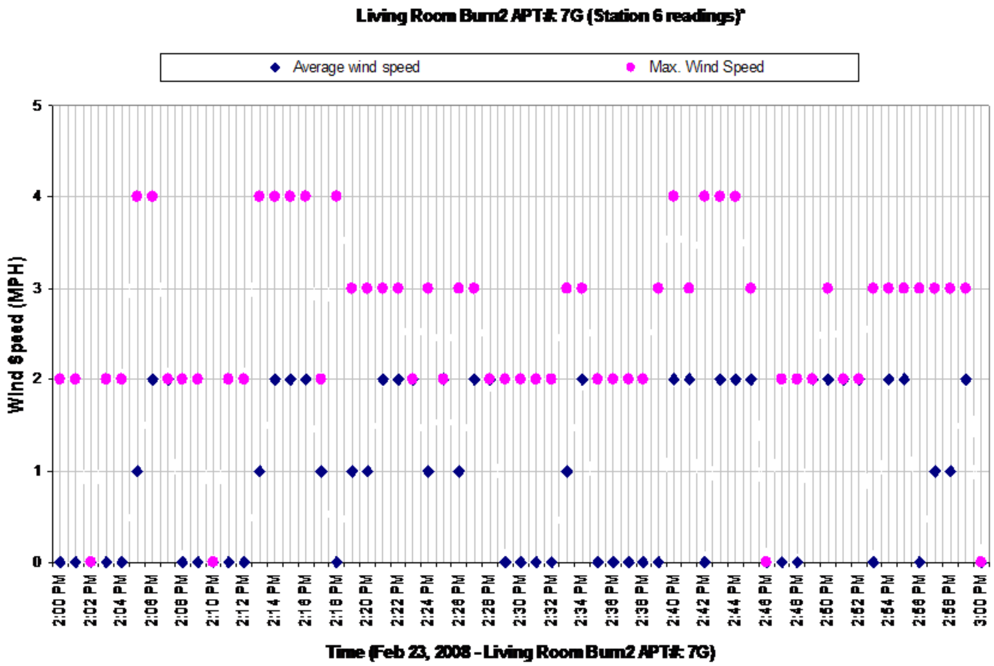

* Station 3 was located on the corner bedroom window along shorter side of apt #: 5G



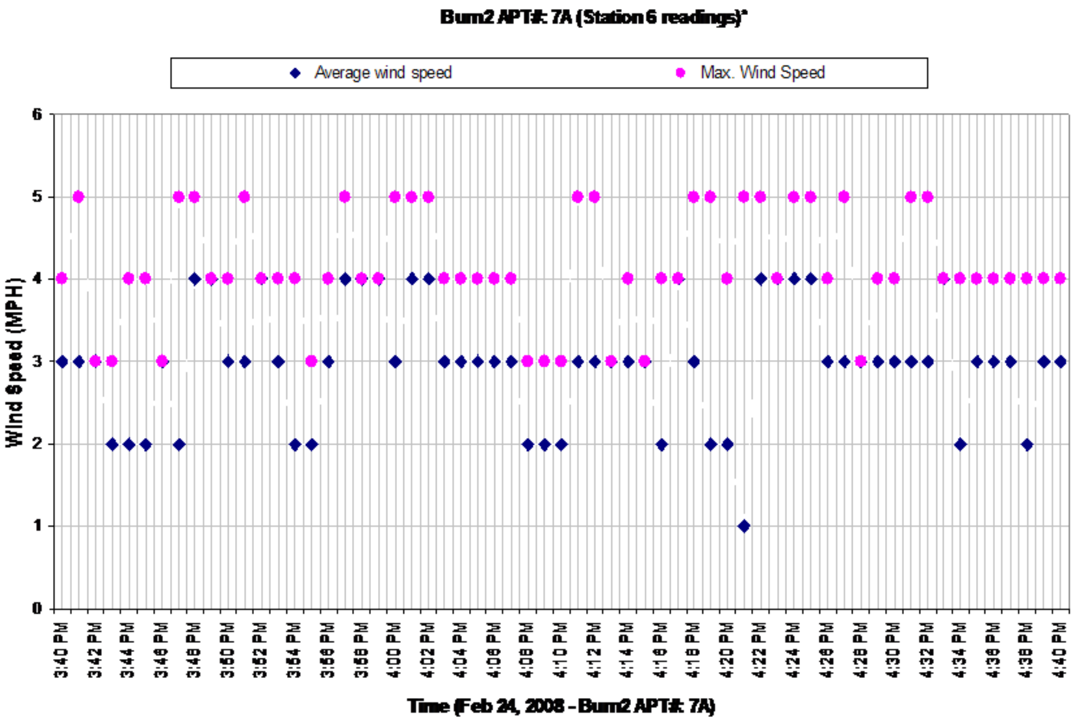

* Station 4 was located on the living room window along longer side of apt# 5G




* Station 5 was located on the ground in front of building #844




* Station 6 was located on the ground at back side of building #844




* Station 6 was located on the ground at back side of building# 844

# Day 4 – February 24, 2008

•Two burn tests were executed.

•First burn test was conducted in apt # 7E and second burn test was conducted in apt # 7A.

•In all, six weather stations were located at different position around the building # 844 and measuring wind speed and wind directions at respective locations.

•Weather station 1 and weather station 2 were located on the roof of building and measuring external weather conditions

•Weather station 3 and weather station 4 were located along the wall of building # 844 and measuring the wind speed in vertical plane along the wall.

# Day 4 – February 24, 2008

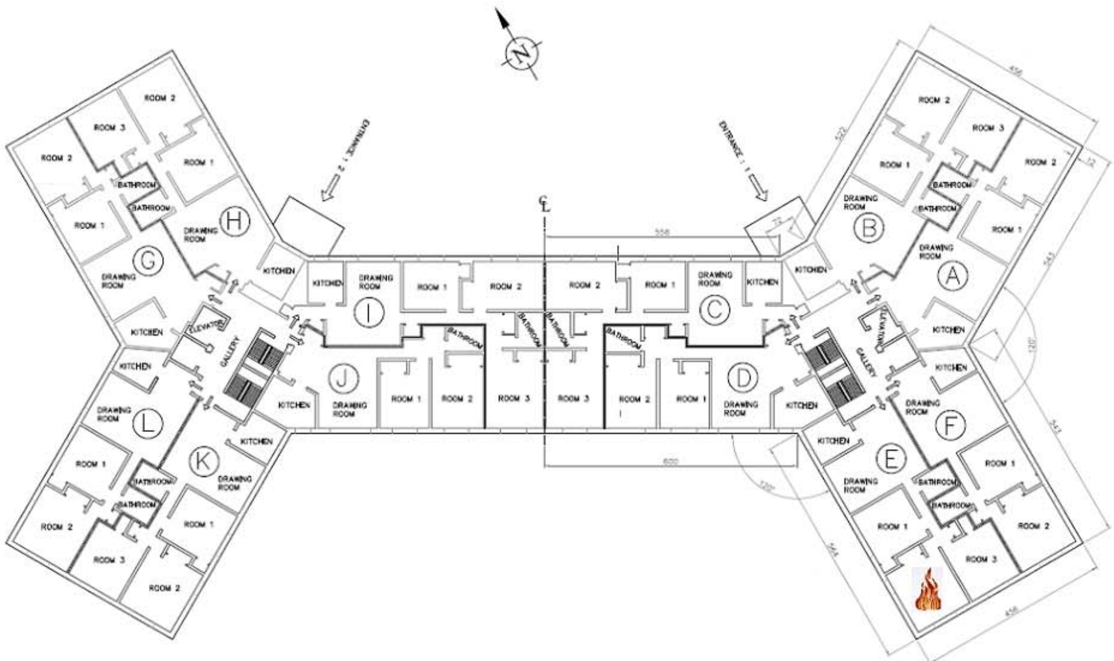
•Weather station 5 and weather station 6 were located on the ground and measuring wind speed in front of the building and on the back side of the building respectively.

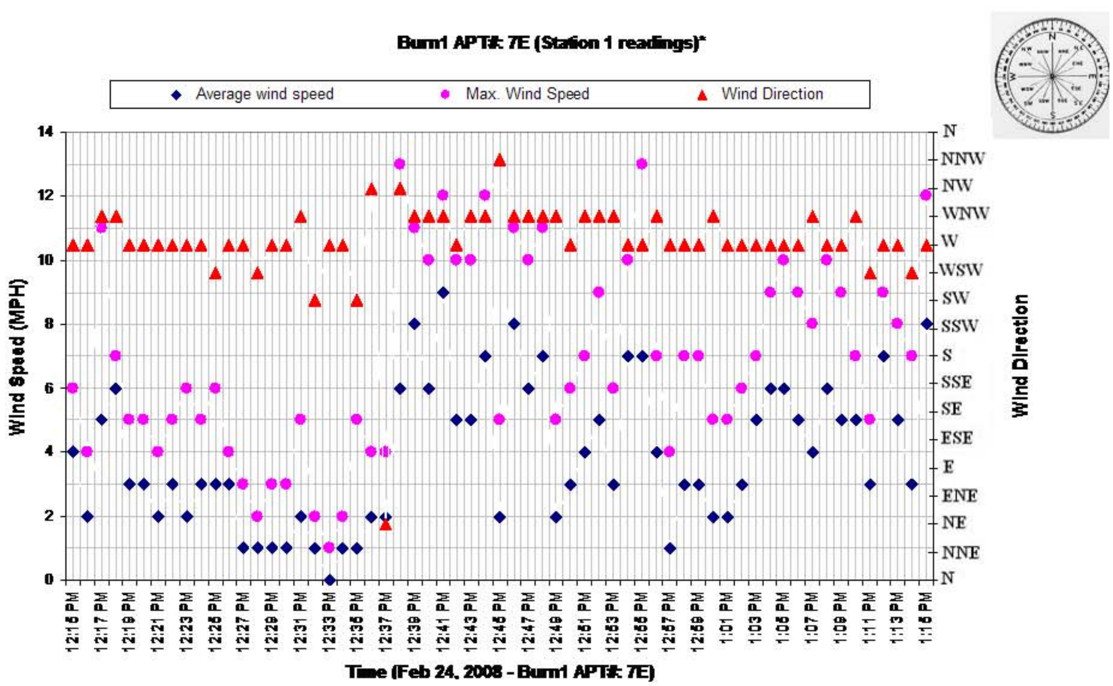
•Readings taken for wind speed, wind direction from respective weather stations for every minute during the period of test have been plotted in following graphs:

•Please note that the specific locations of every weather station has been mentioned at the bottom of respective graph.

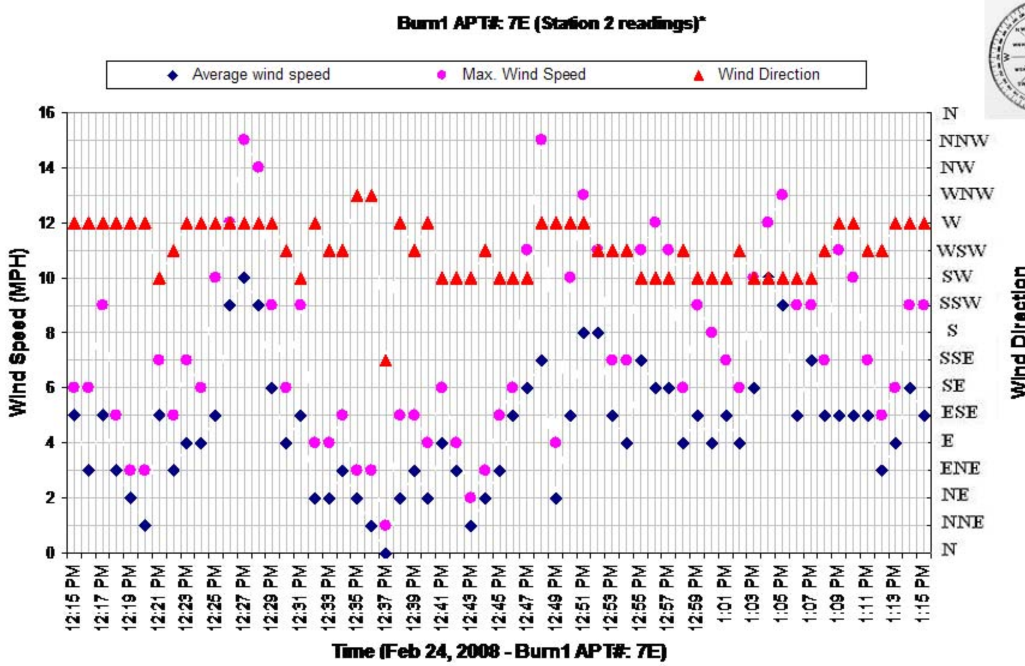
# Day 4 – February 24, 2008

## First burn in apt # 7E

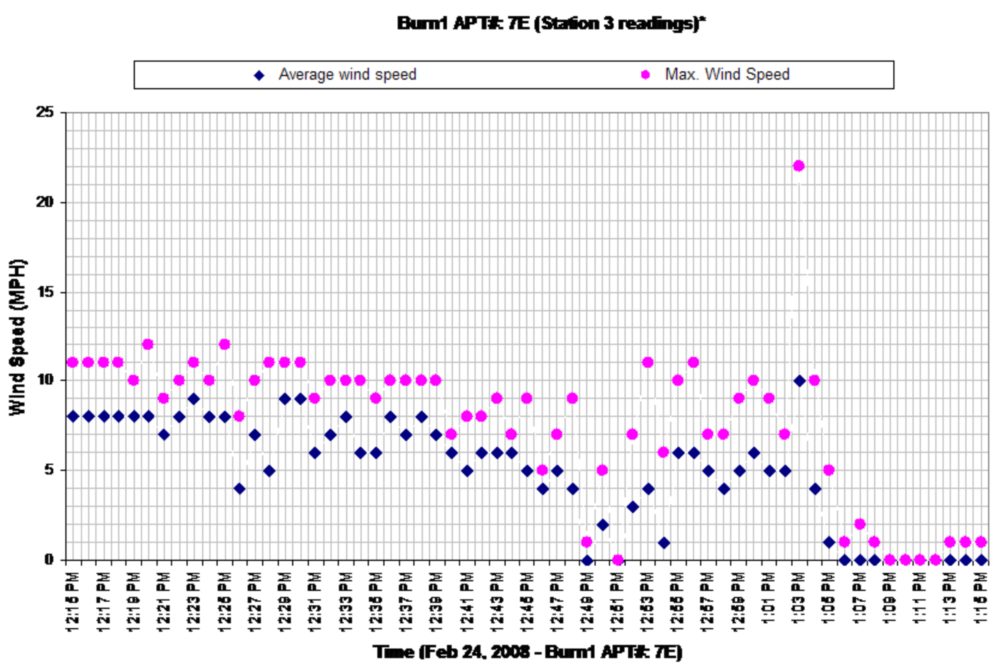




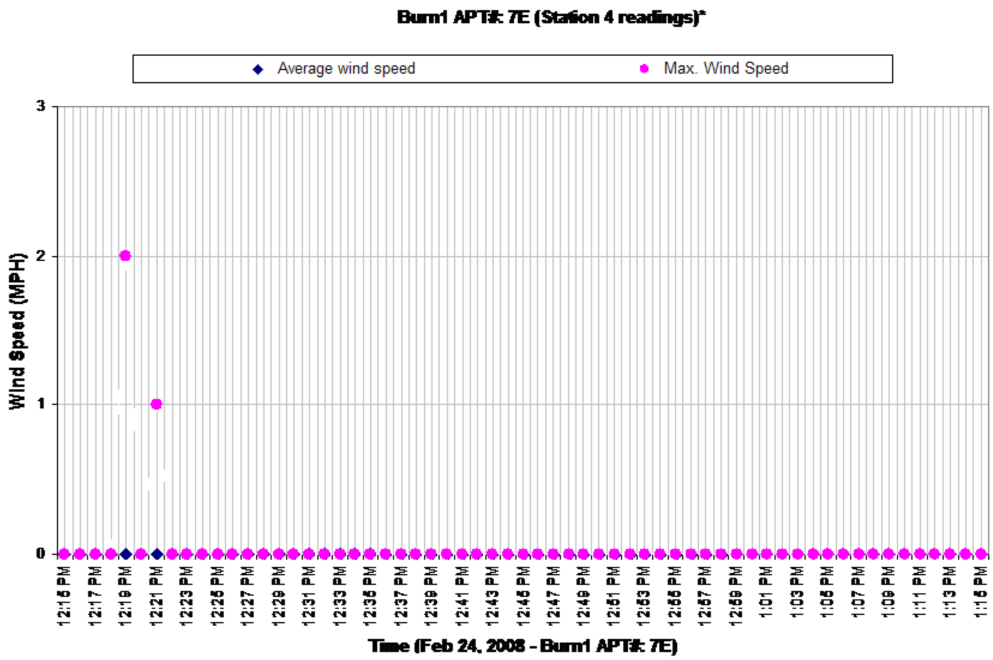

* Station 1 was located on the roof of building #844 : A – F wing



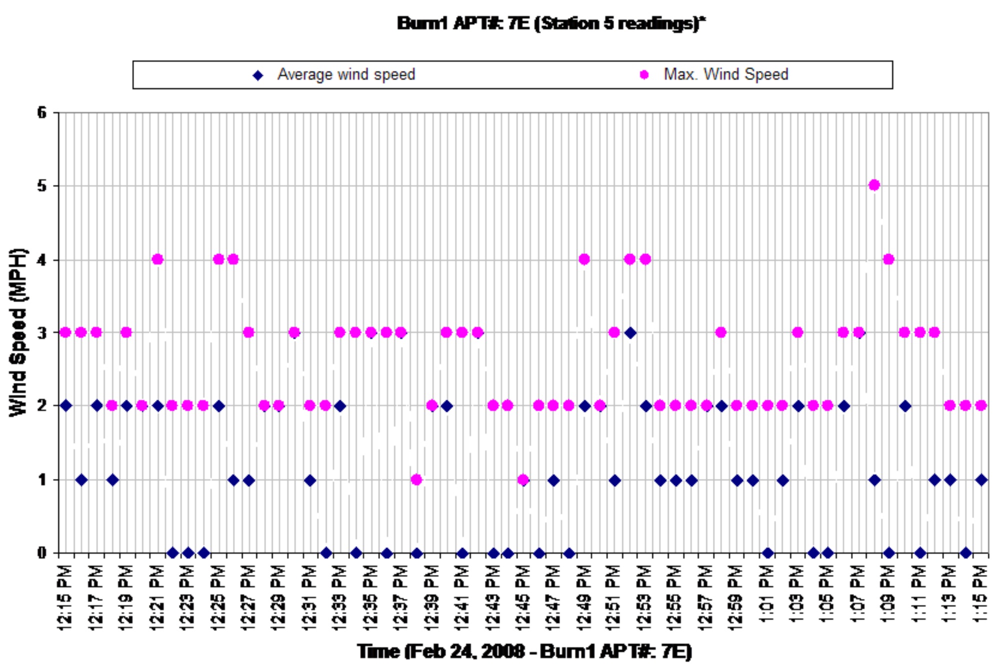

* Station 2 was located on the roof of building #844 : G – L wing



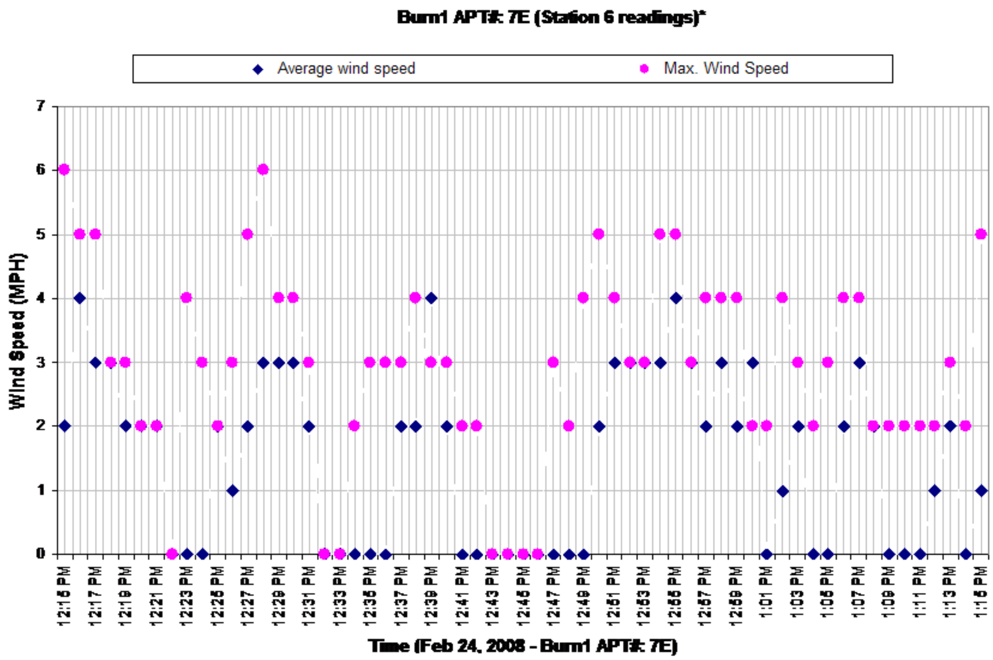

* Station 3 was located on the corner bedroom window along shorter side of apt# 5E




* Station 4 was located on the living room window along longer side of apt# 5E



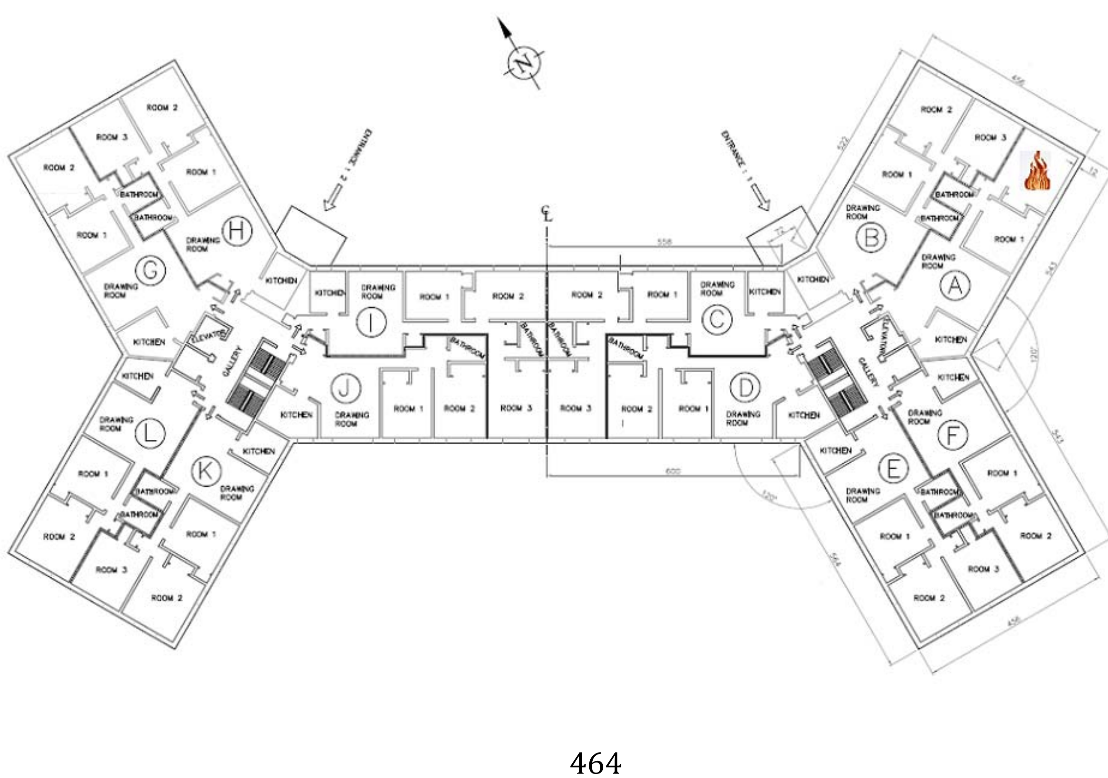

* Station 5 was located on the ground in front of building# 844

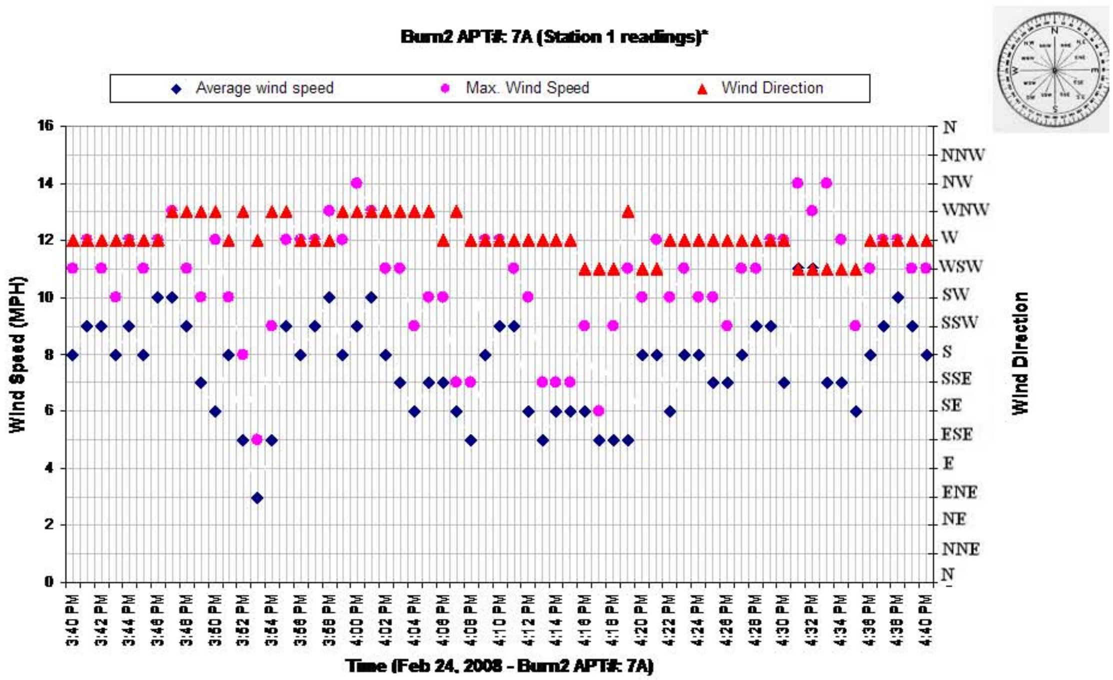



* Station 6 was located on the ground of building# 844

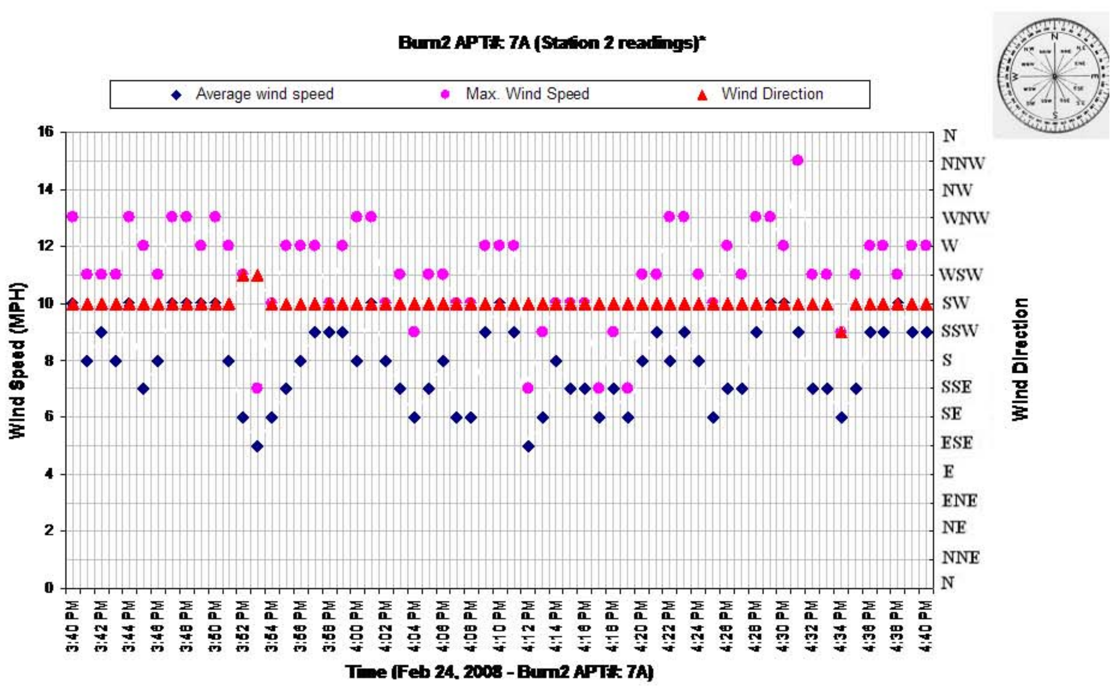
# Day 4 – February 24, 2008

## Second burn in apt # 7A

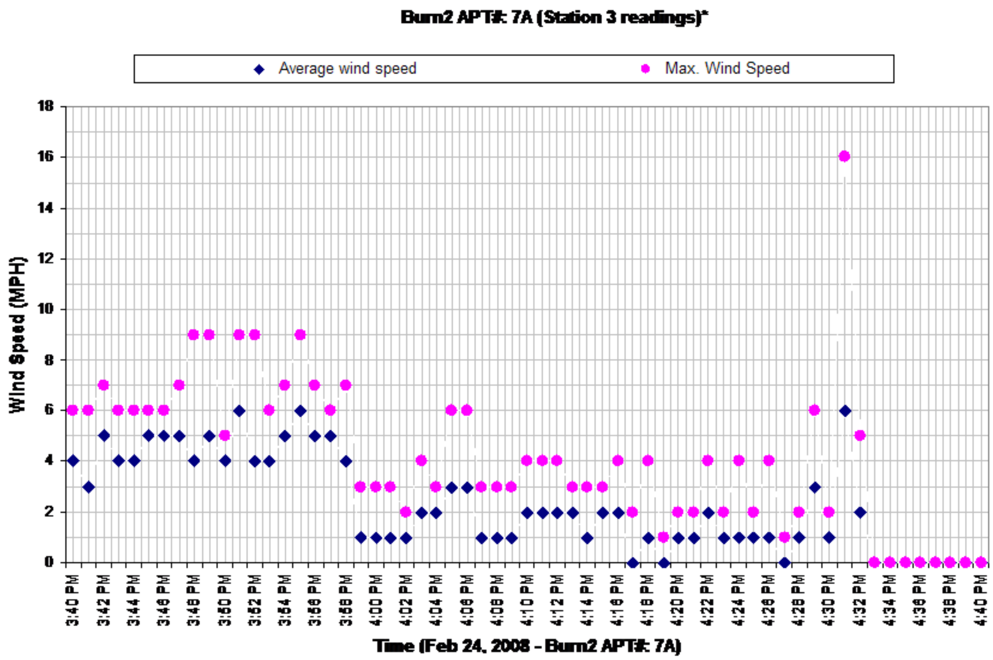




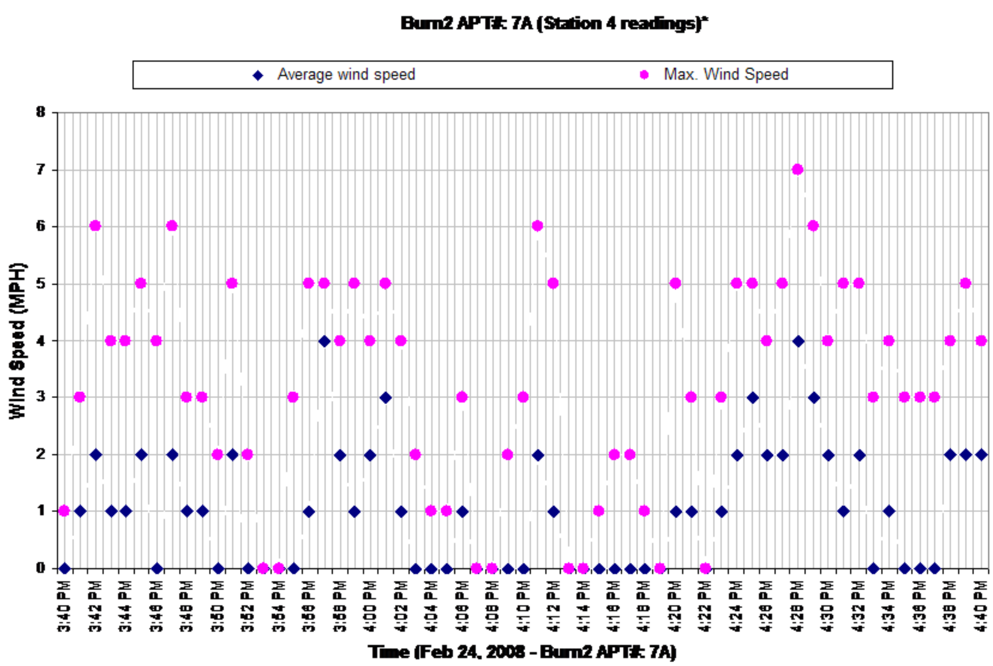

* Station 1 was located on the roof of building #844 : A – F wing



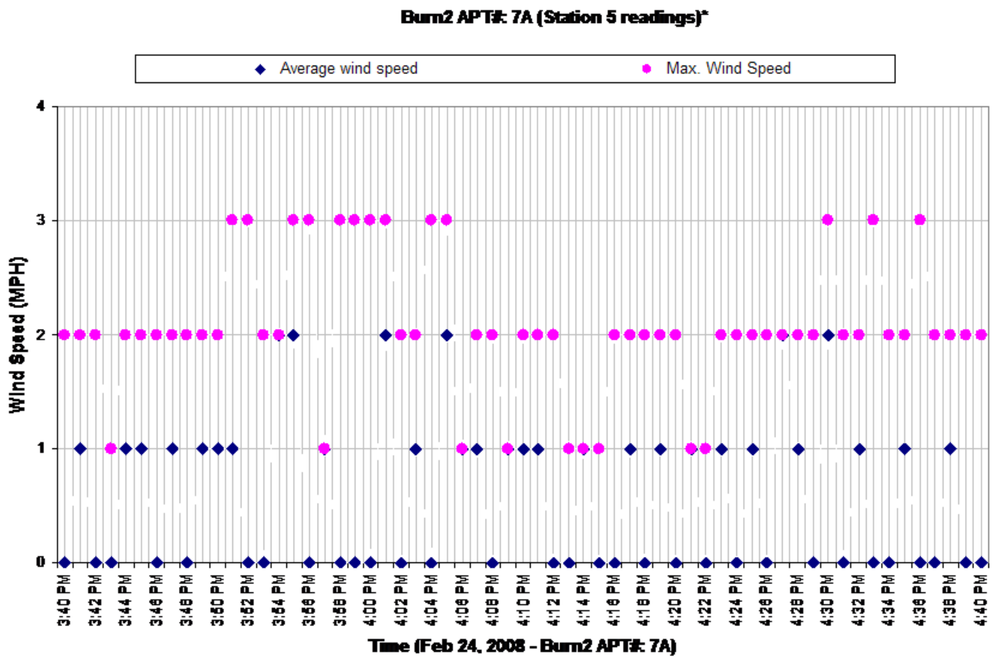

* Station 2 was located on the roof of building #844 : G – L wing




* Station 3 was located on the corner bedroom window along shorter side of apt#5A




* Station 4 was located on the living room window along longer side of apt# 5A




* Station 5 was located on the ground in front of building# 844

# Day 5 – February 25, 2008

•One burn test was conducted in apt # 7K.

•In all, six weather stations were located at different position around the building # 844 and measuring wind speed and wind directions at respective locations.

•Weather station 1 and weather station 2 were located on the roof of building and measuring external weather conditions

•Weather station 3 and weather station 4 were located along the wall of building # 844 and measuring the wind speed in vertical plane along the wall.

# Day 5 – February 25, 2008

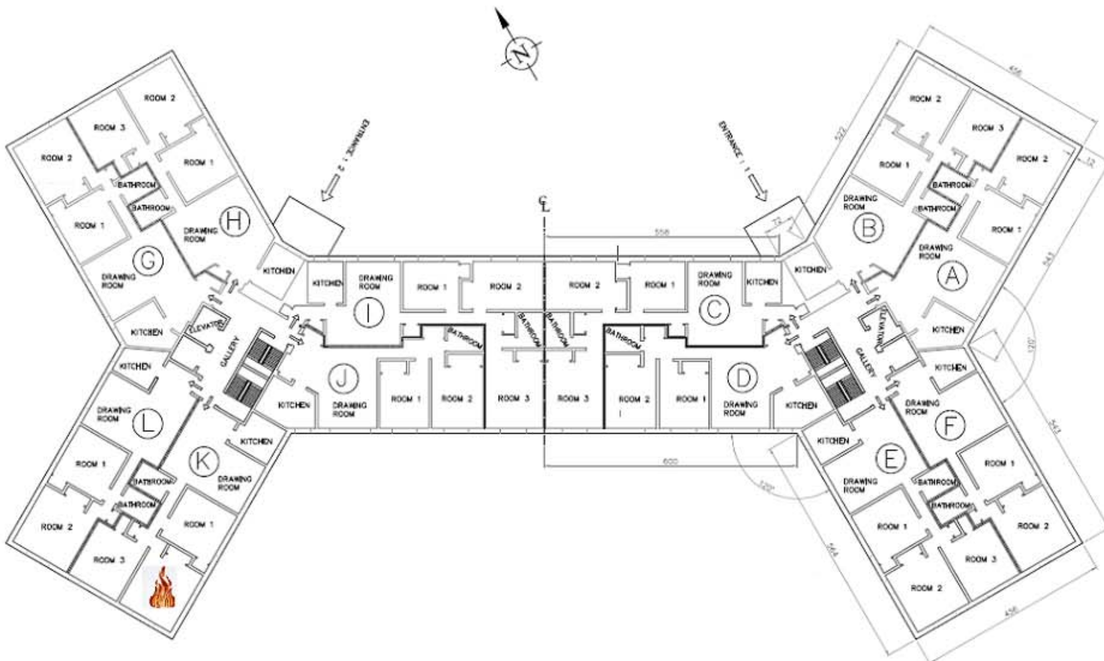
•Weather station 5 and weather station 6 were located on the ground and measuring wind speed in front of the building and on the back side of the building respectively.

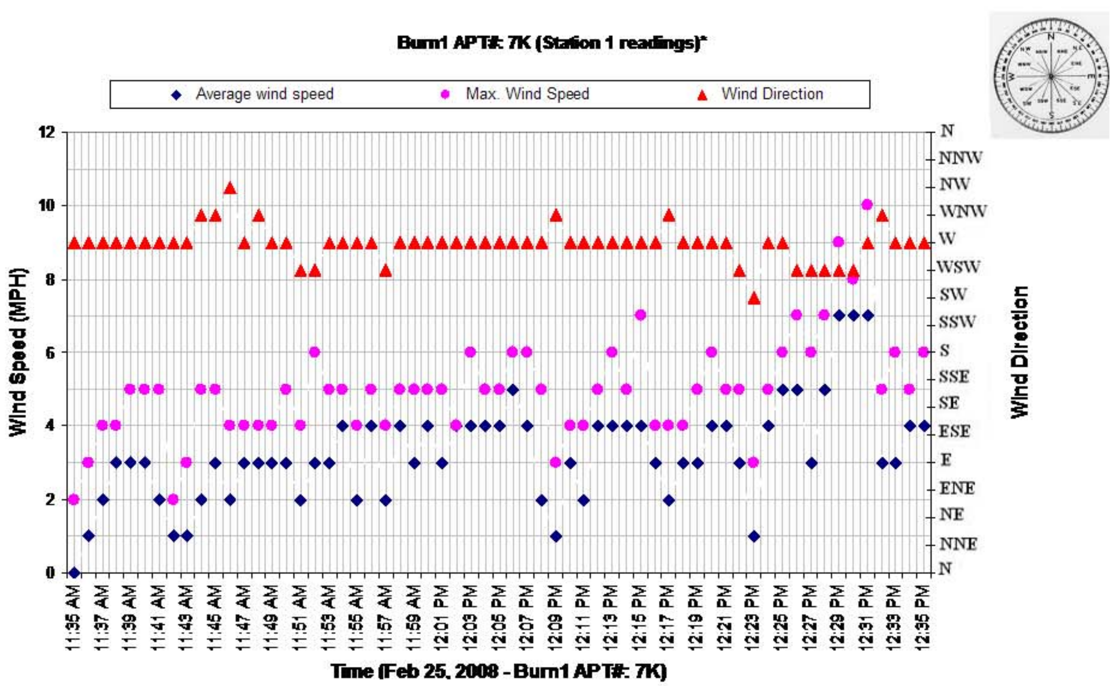
•Readings taken for wind speed, wind direction from respective weather stations for every minute during the period of test have been plotted in following graphs:

•Please note that the specific locations of every weather station has been mentioned at the bottom of respective graph.

# Day 5 – February 25, 2008

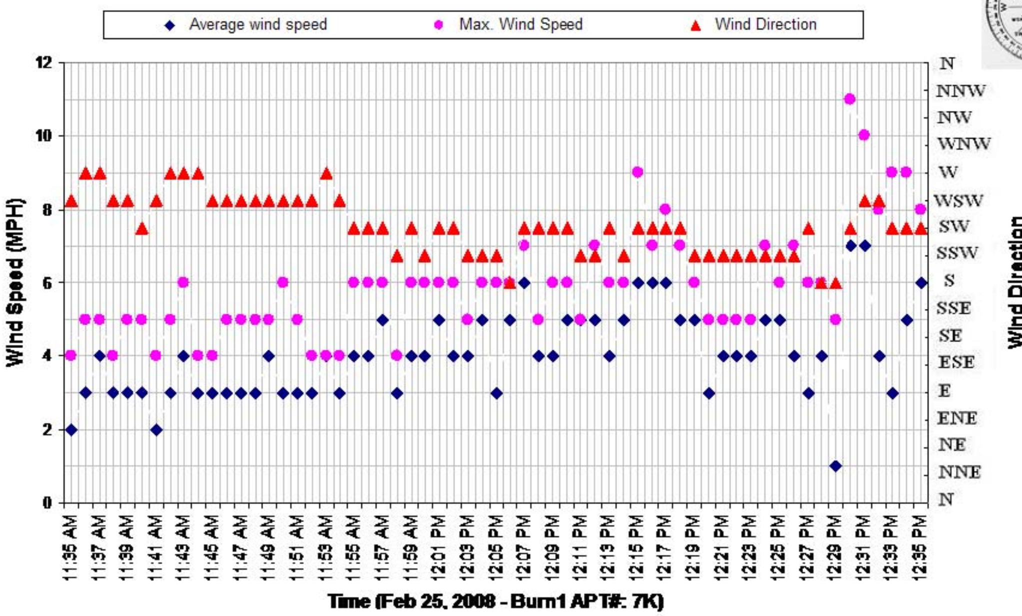
## Burn in apt # 7K

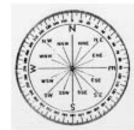



* Station 1 was located on the roof of building #844 : A – F wing

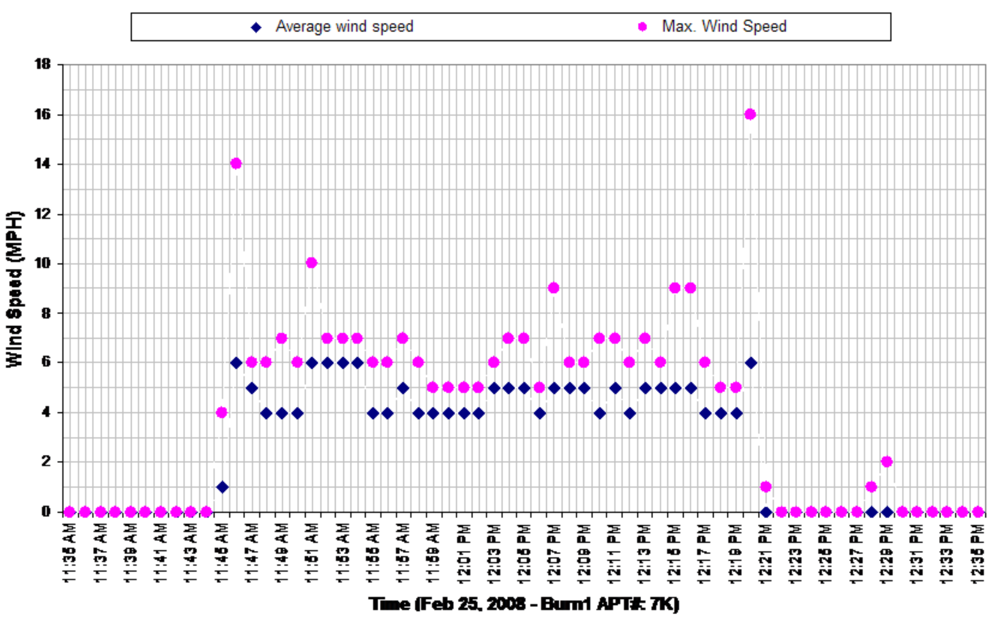
**Burn1 APT#: 7K (Station 2 readings)***



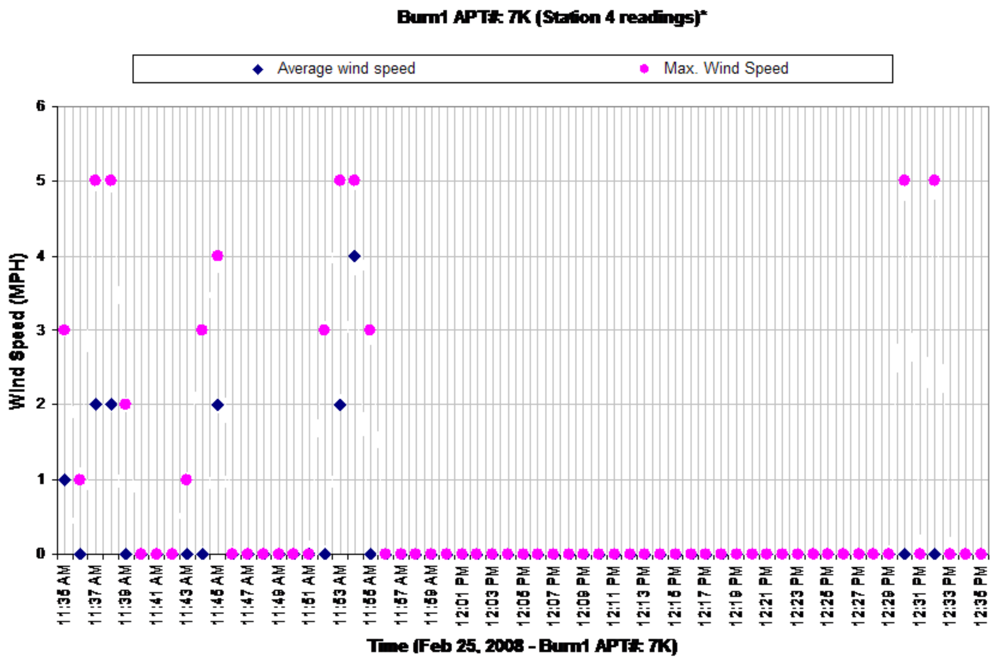



* Station 2 was located on the roof of building #844 : G – L wing

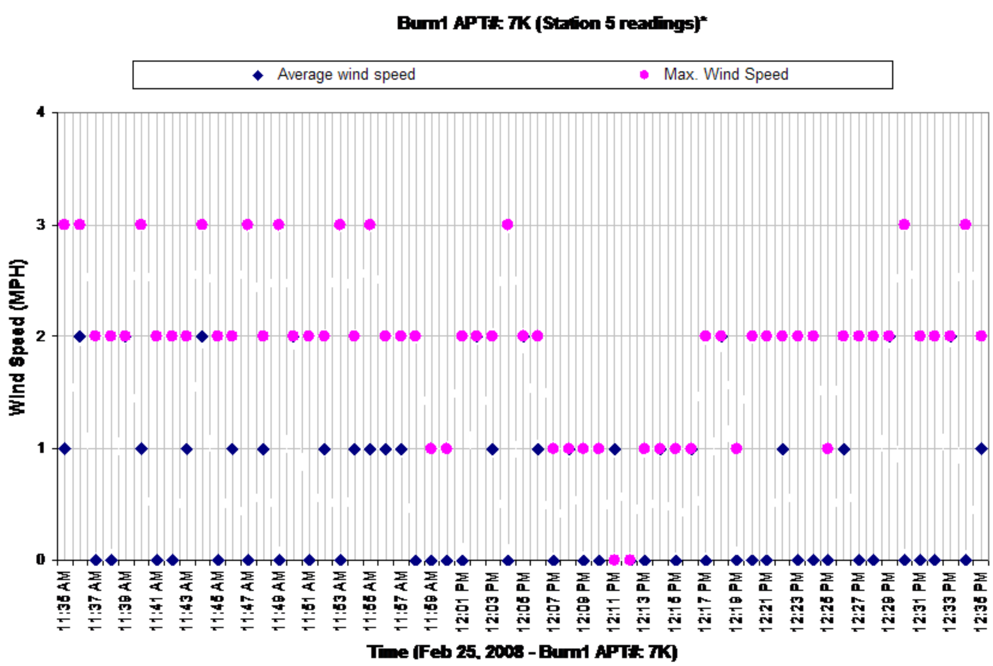
**Burn1 APT#: 7K (Station 3 readings)***



* Station 3 was located on the corner bedroom window along shorter side of apt# 5K

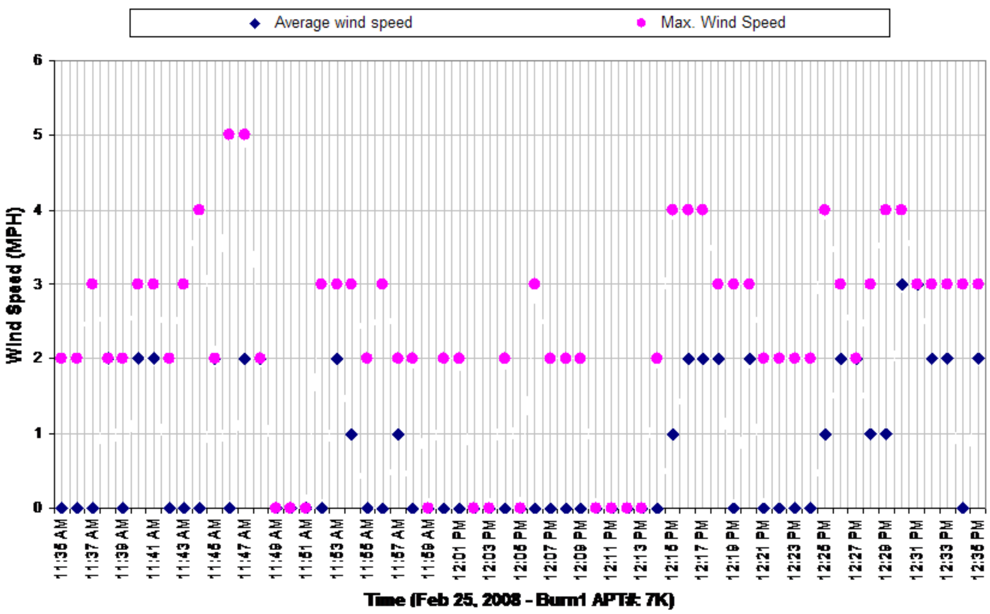



* Station 4 was located on the living room window along longer side of apt#7K




* Station 5 was located on the ground in front of building #844

Burn1 APT#: 7K (Station 6 readings)*




* Station 6 was located on the ground at back side of building#844

# Day 6 – February 26, 2008

•Two burn tests were executed.

•First burn test was conducted in apt # 5E and second burn test was conducted in apt # 5K.

•In all, six weather stations were located at different position around the building # 844 and measuring wind speed and wind directions at respective locations.

•Weather station 1 and weather station 2 were located on the roof of building and measuring external weather conditions

•Weather stations 3, 4, 5 and 6 were located along the wall of building # 844 and measuring the wind speed in vertical plane along the wall.

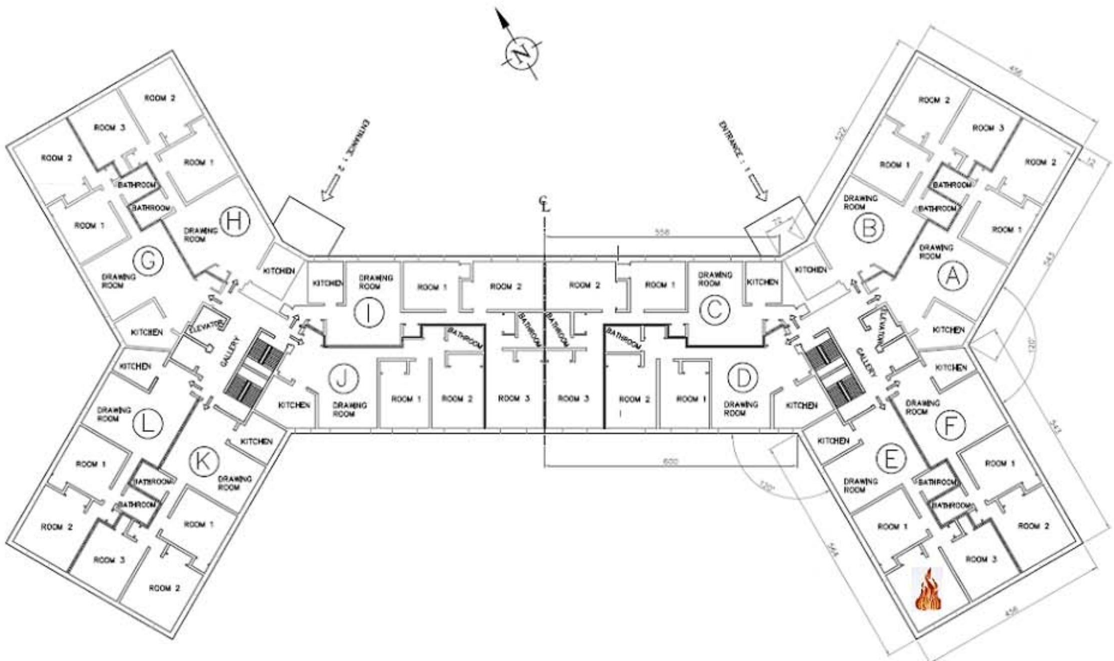
# Day 6 – February 26, 2008

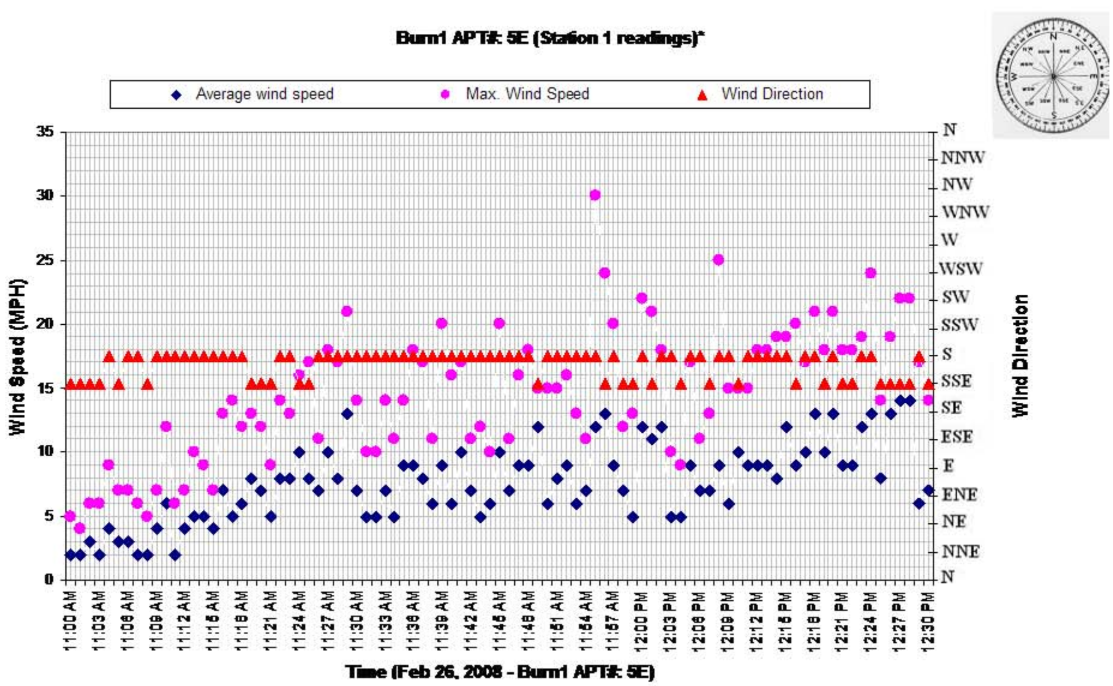
•Readings taken for wind speed, wind direction from respective weather stations for every minute during the period of test have been plotted in following graphs:

•Please note that the specific locations of every weather station has been mentioned at the bottom of respective graph.

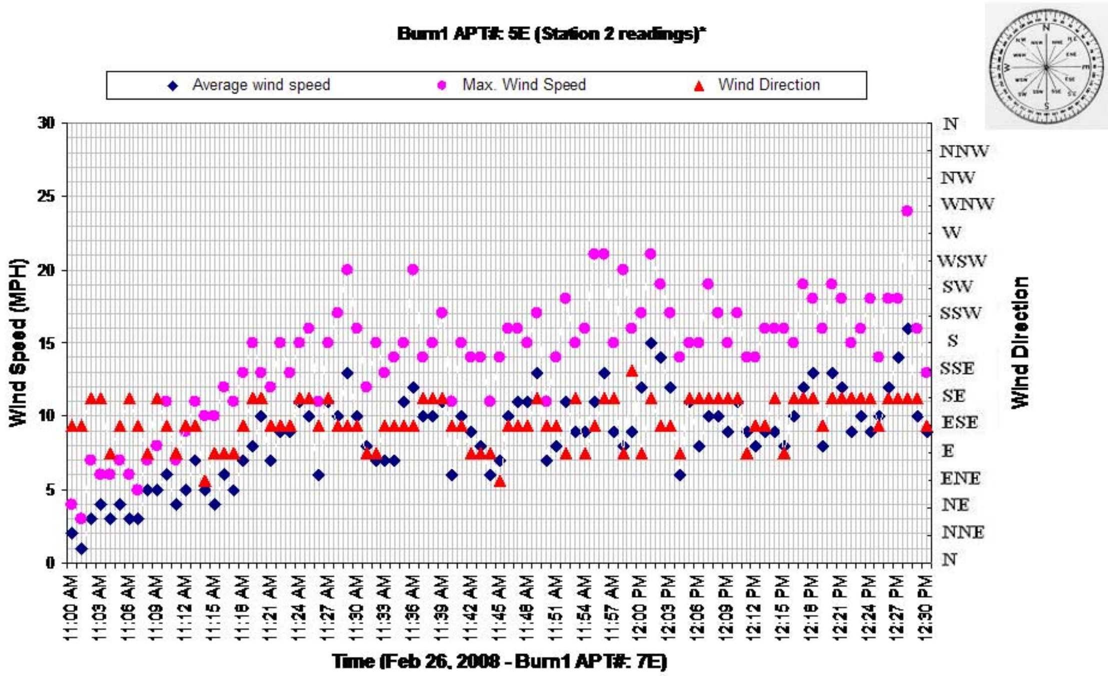
# Day 6 – February 26, 2008

## First burn in apt # 5E

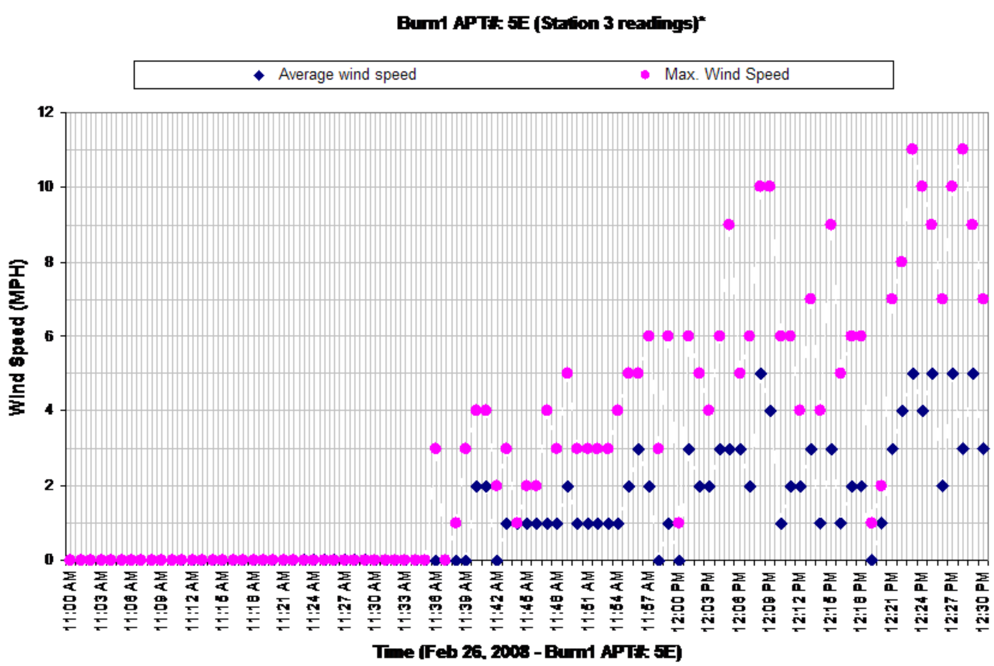




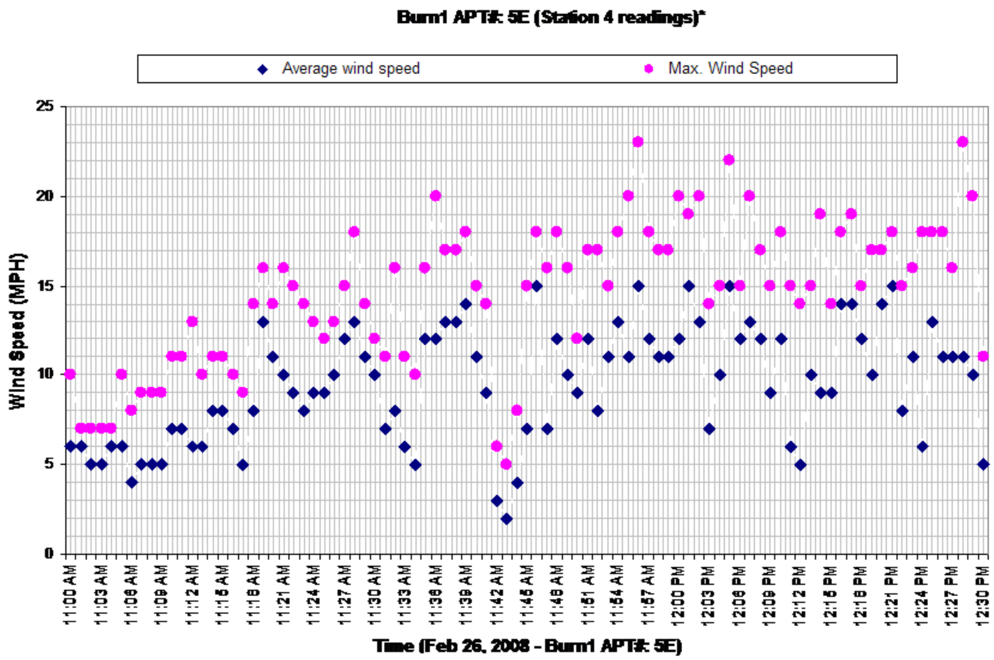

* Station 1 was located on the roof of building #844 : A – F wing



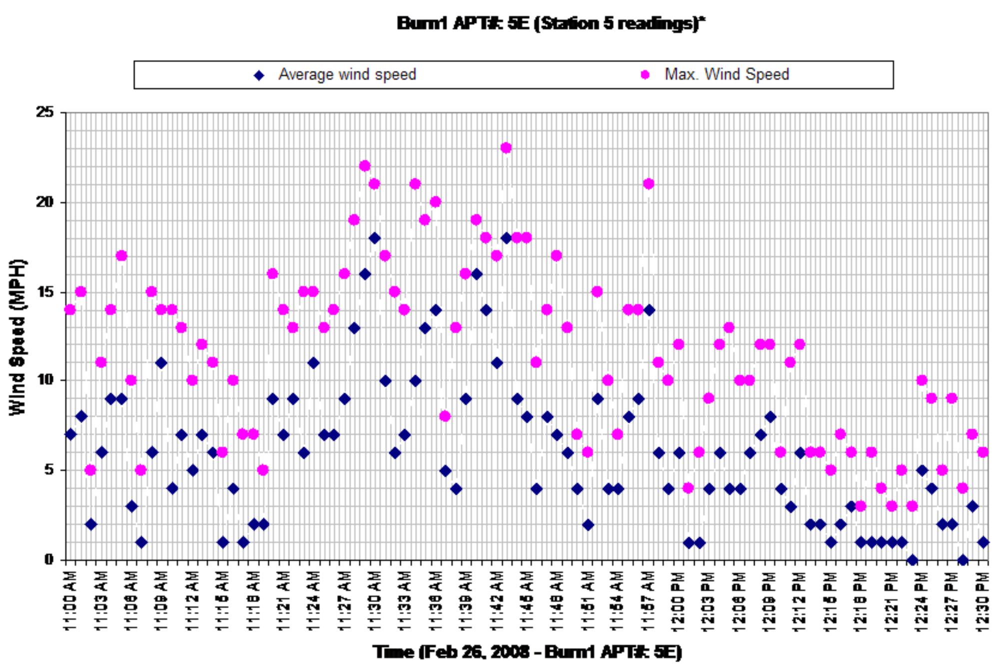

* Station 2 was located on the roof of building #844 : G – L wing



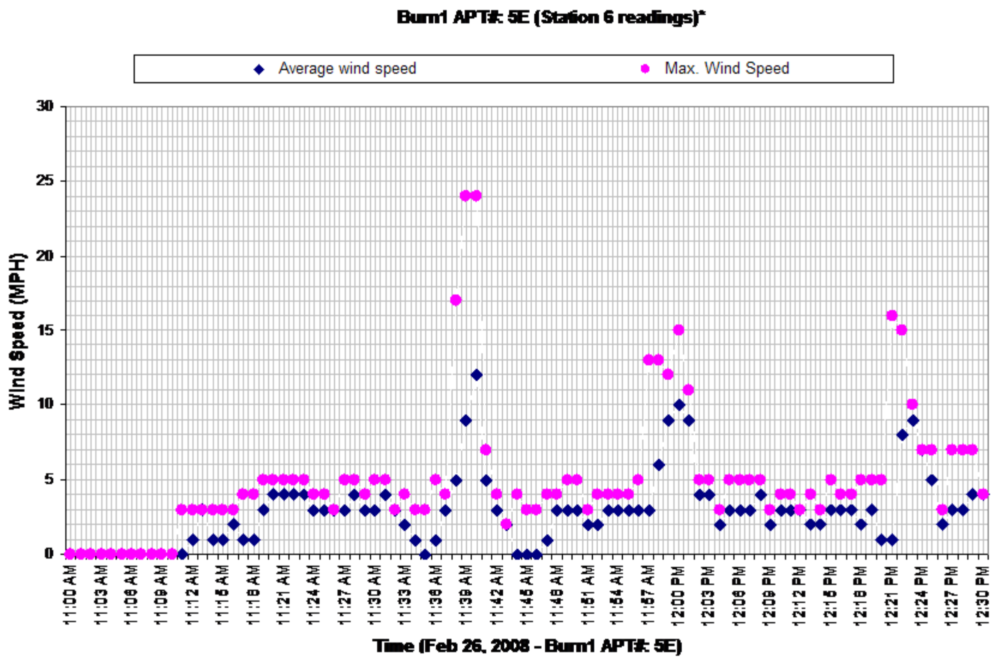

* Station 3 was located on the living room window along longer side of apt# 7E




* Station 4 was located on the corner bedroom window along shorter side of apt# 7E



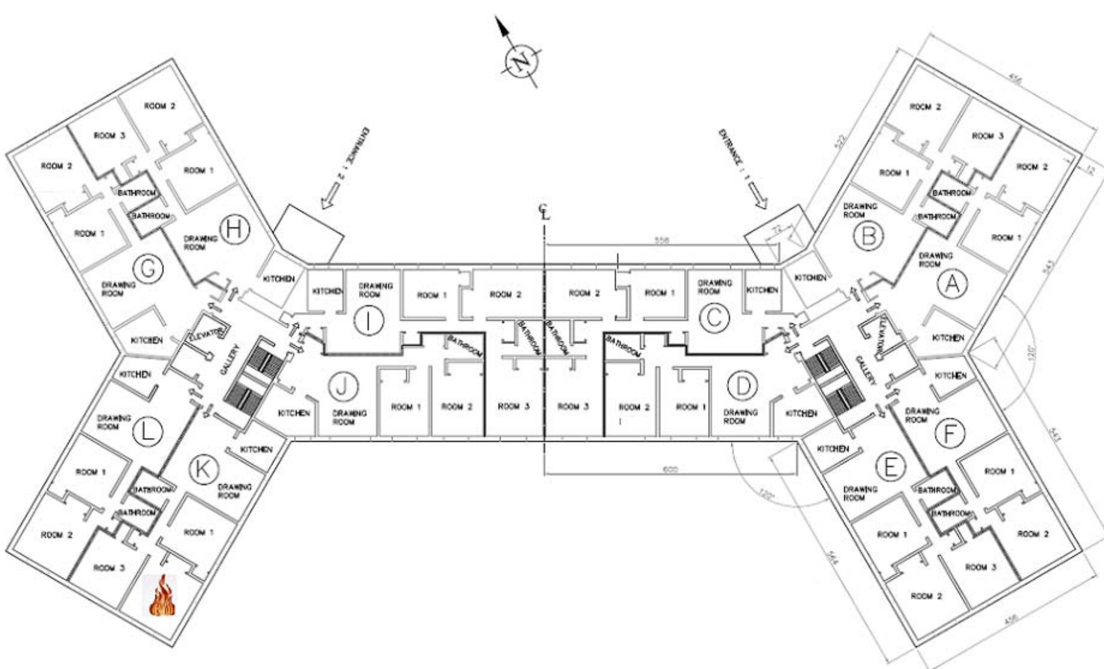

* Station 5 was located on the corner bedroom window along shorter side of apt# 3E

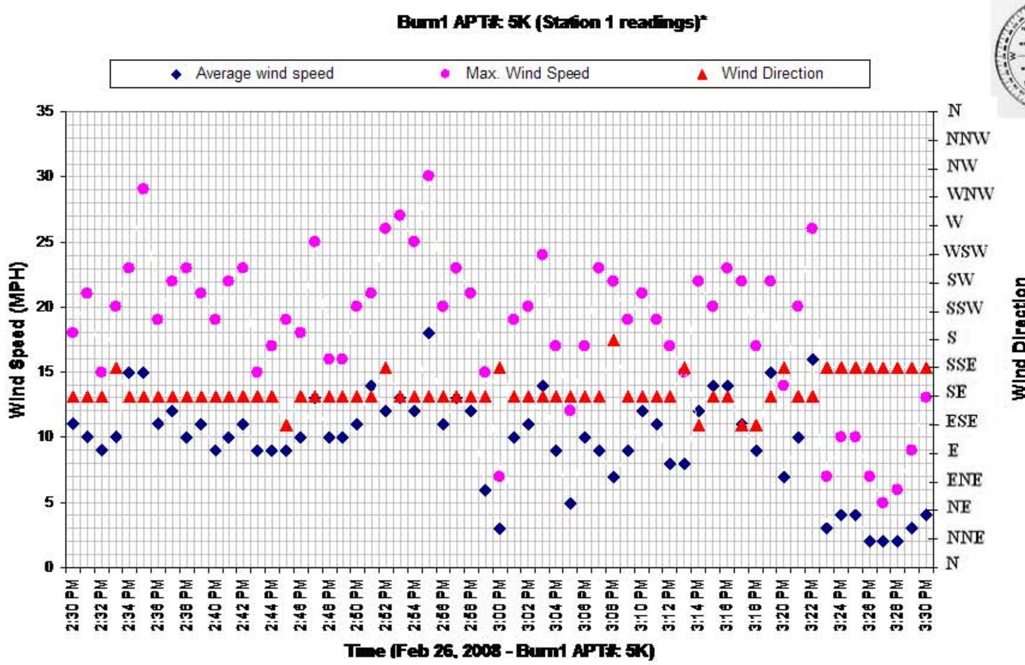


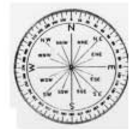

* Station 6 was located on the living room window along longer side of apt#3E

# Day 6 – February 26, 2008

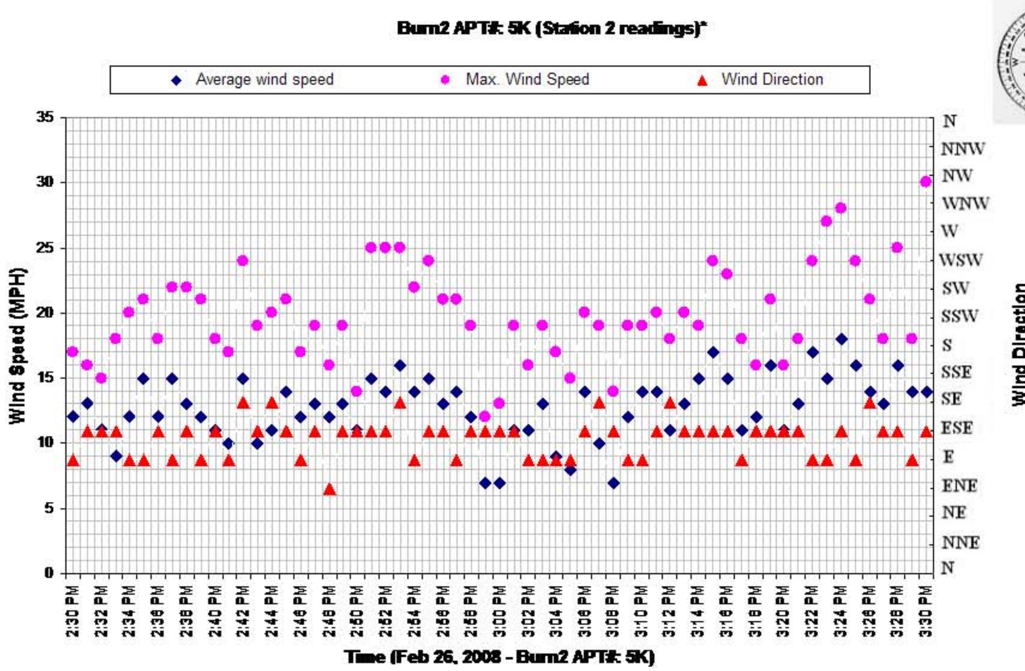
## Second burn in apt # 5K

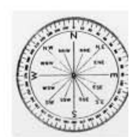




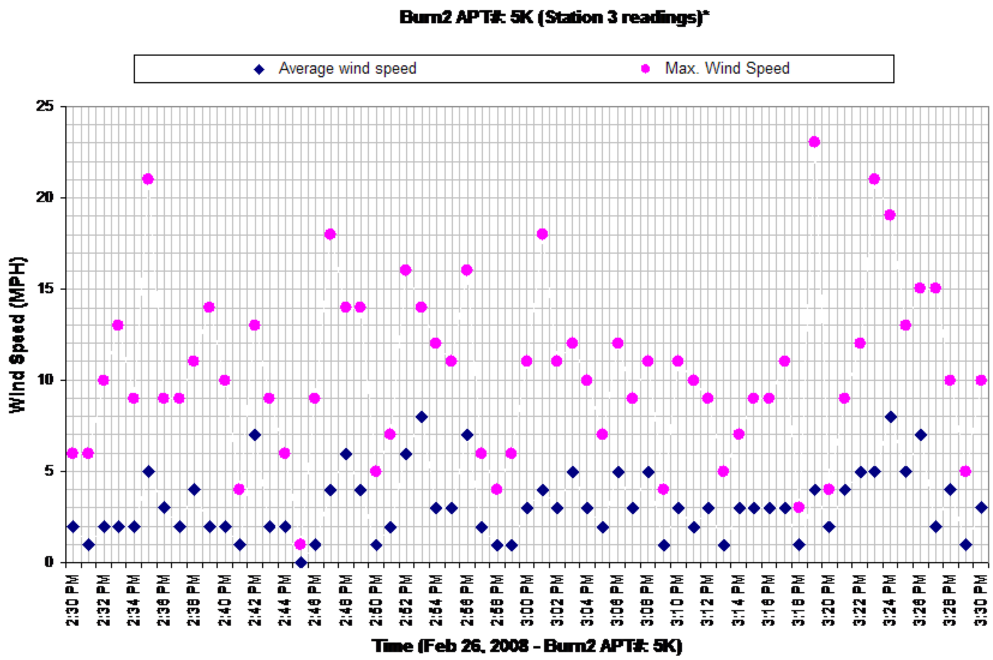



* Station 1 was located on the roof of building #844 : A – F wing

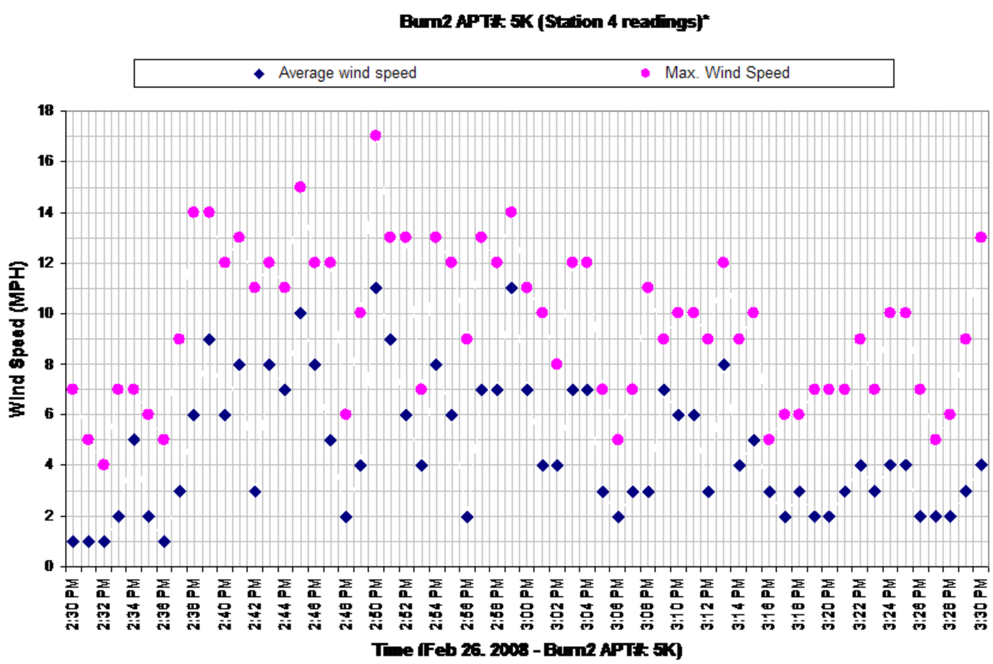


* Station 2 was located on the roof of building #844 : G – L wing

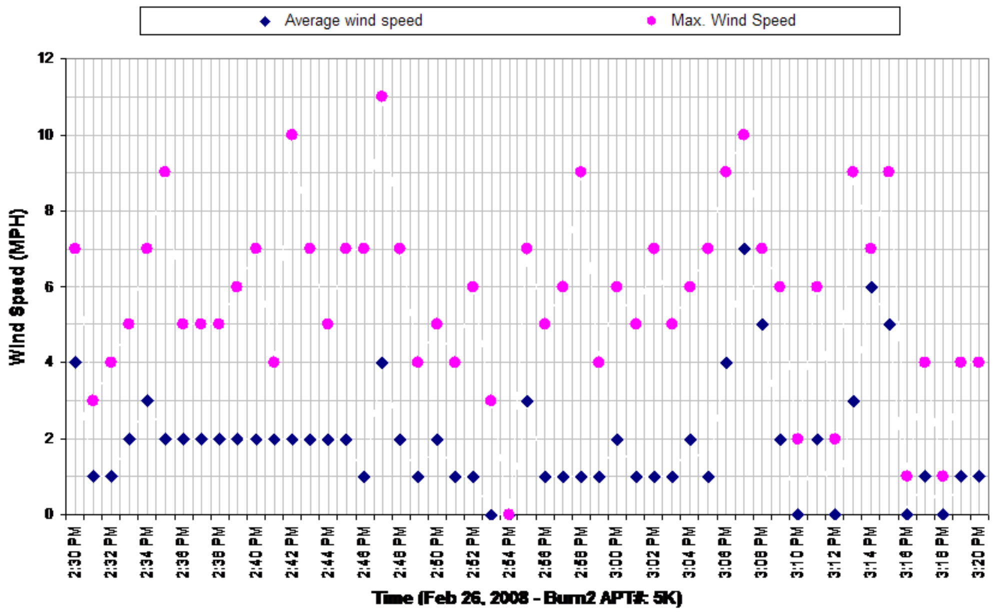



* Station 3 was located on the living room window along longer side of apt# 7K



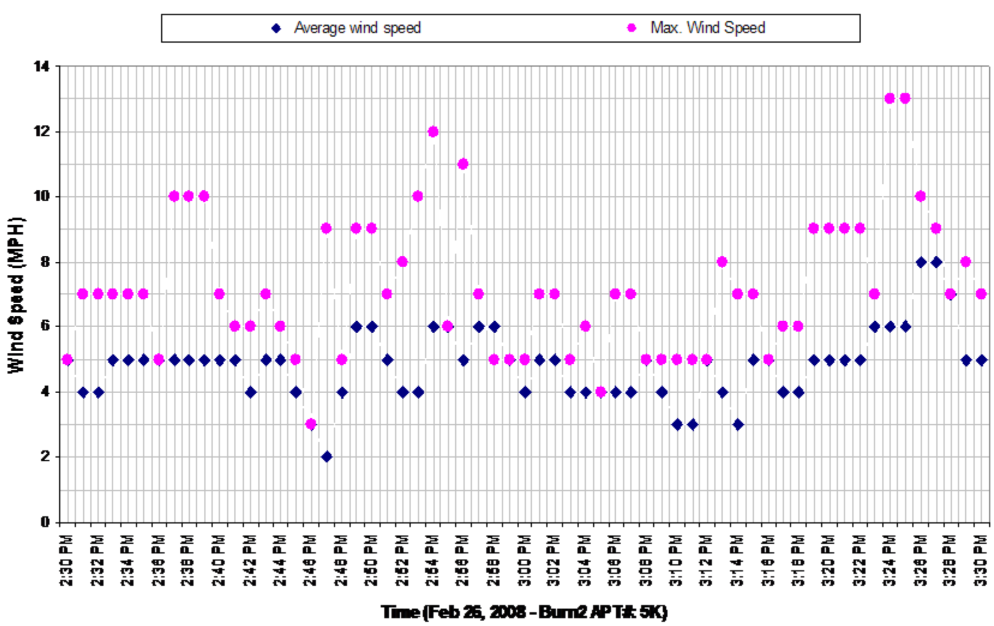

* Station 4 was located on the corner bedroom window along shorter side of apt#7K

**Burn2 APT#: 5K (Station 5 readings)***




* Station 5 was located on the corner bedroom window along shorter side of apt#3K

**Burn2 APT#: 5K (Station 6 readings)***




* Station 6 was located on the living room window along longer side of apt#3K

# Day 7 – February 27, 2008

•Two burn tests were executed.

•First burn test was conducted in apt # 5A and second burn test was conducted in apt # 5G.

•In all, six weather stations were located at different position around the building # 844 and measuring wind speed and wind directions at respective locations.

•Weather station 1 and weather station 2 were located on the roof of building and measuring external weather conditions

•Weather stations 3, 4, 5 and 6 were located along the wall of building # 844 and measuring the wind speed in vertical plane along the wall.

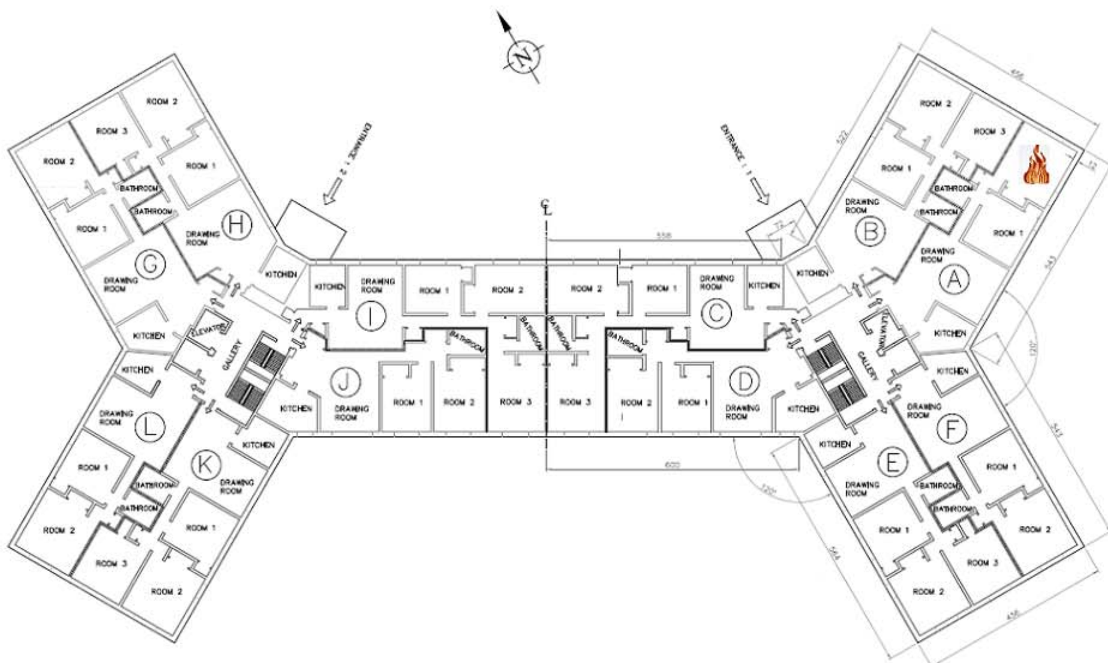
# Day 7 – February 27, 2008

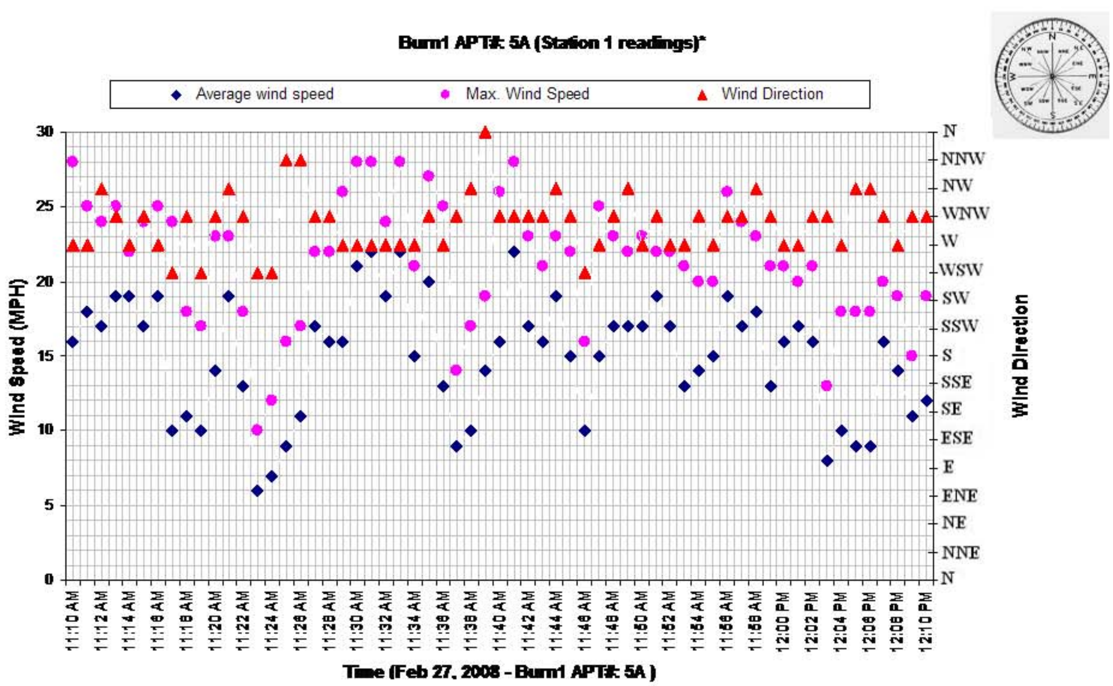
•Readings taken for wind speed, wind direction from respective weather stations for every minute during the period of test have been plotted in following graphs:

•Please note that the specific locations of every weather station has been mentioned at the bottom of respective graph.

# Day 7 – February 27, 2008

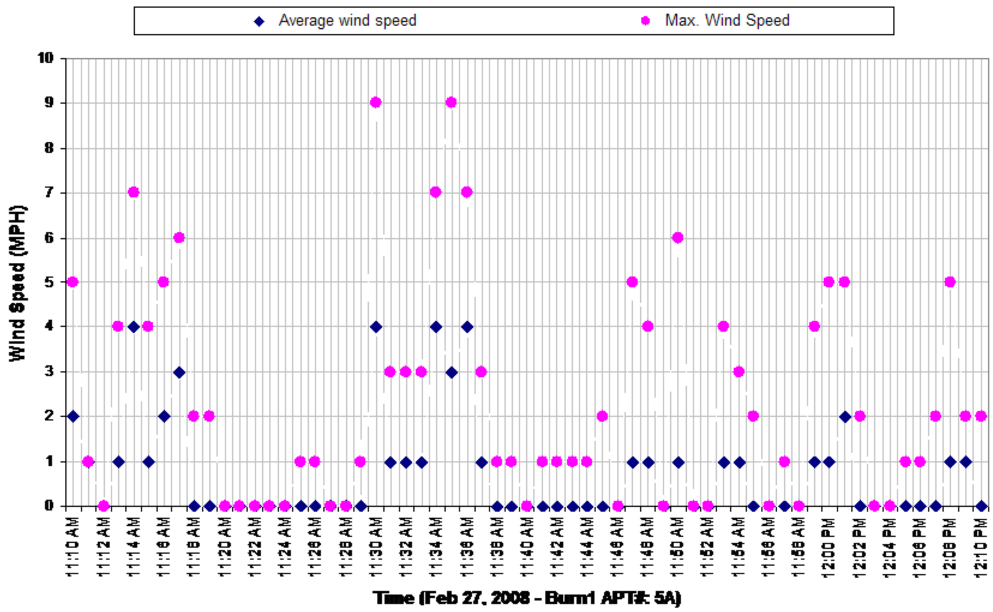
## First burn in apt # 5A





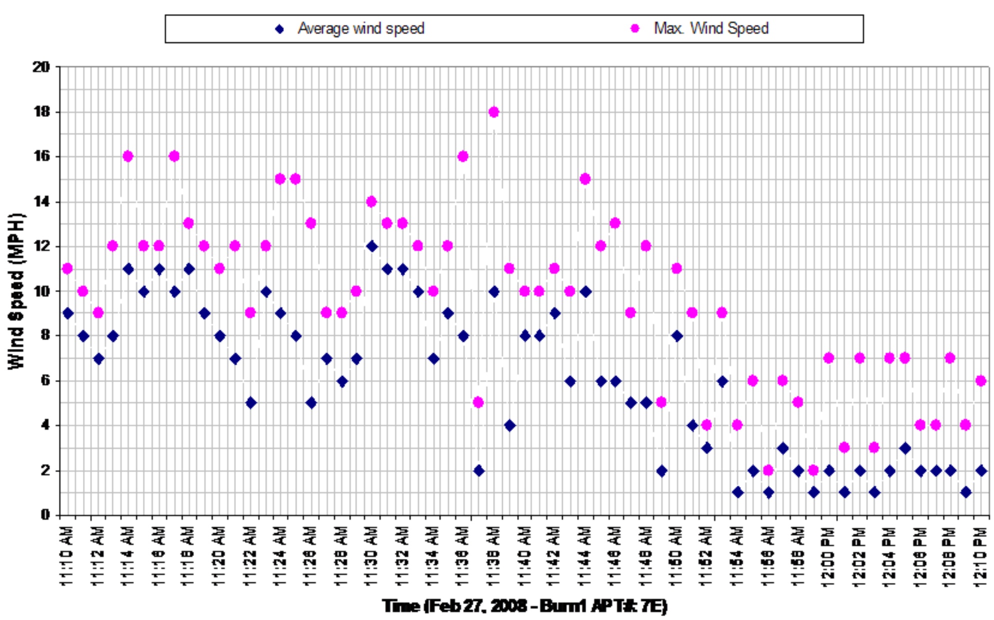

* Station 1 was located on the roof of building #844 : A – F wing

Burn1 APT#: 5A (Station 3 readings)*



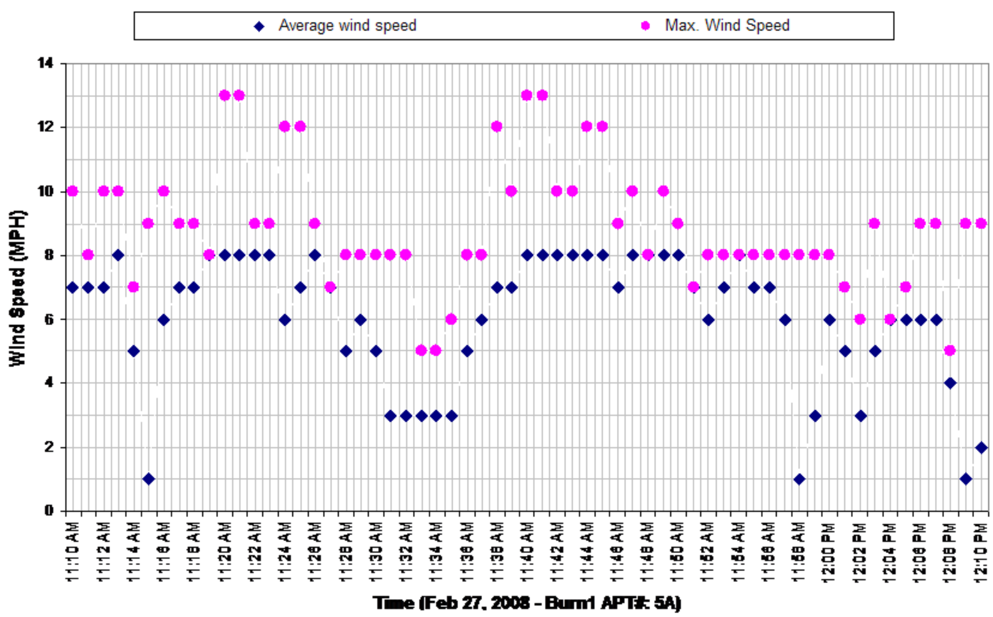

* Station 3 was located on the corner bedroom window along shorter side of apt#7A

Burn1 APT#: 7E (Station 4 readings)*



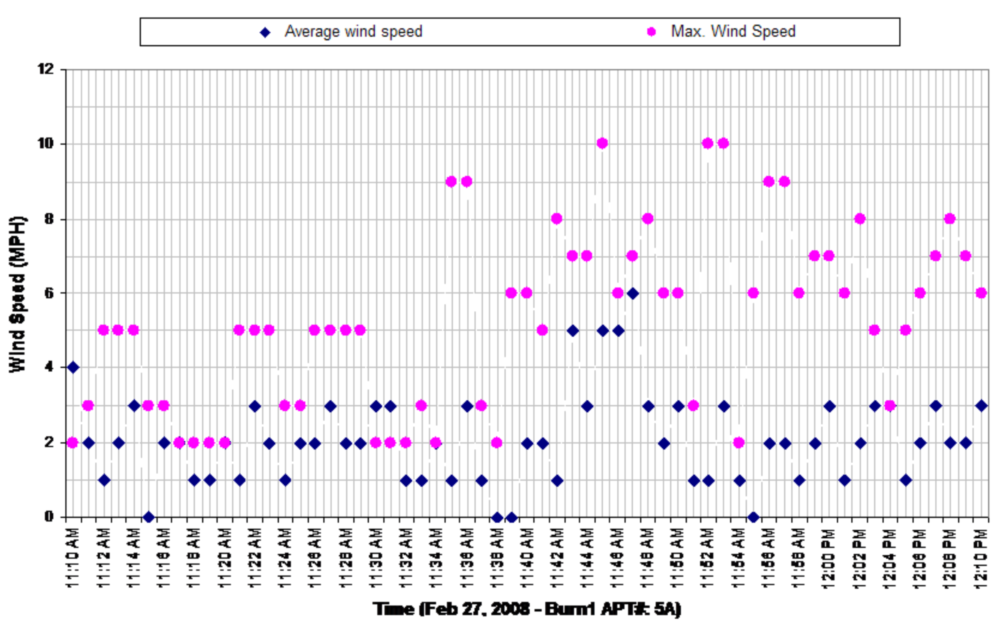

* Station 4 was located on the living room window along longer side of apt#5E

**Burn1 APT#: 5A (Station 5 readings)***




* Station 5 was located on the corner bedroom window along shorter side of apt#3A

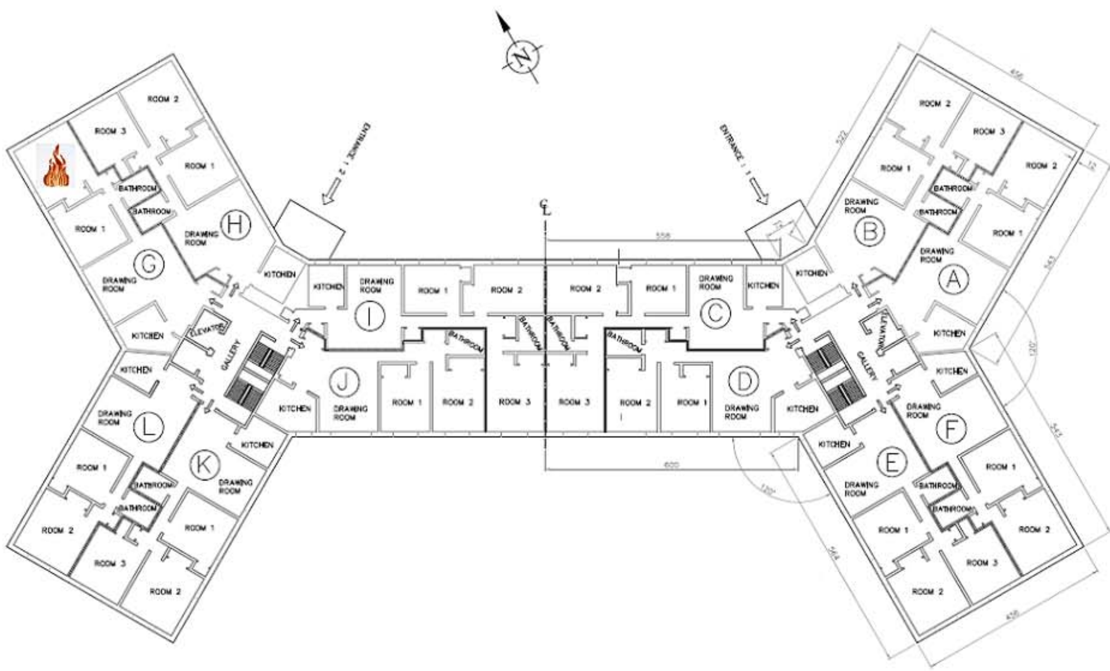
**Burn1 APT#: 5A (Station 6 readings)***

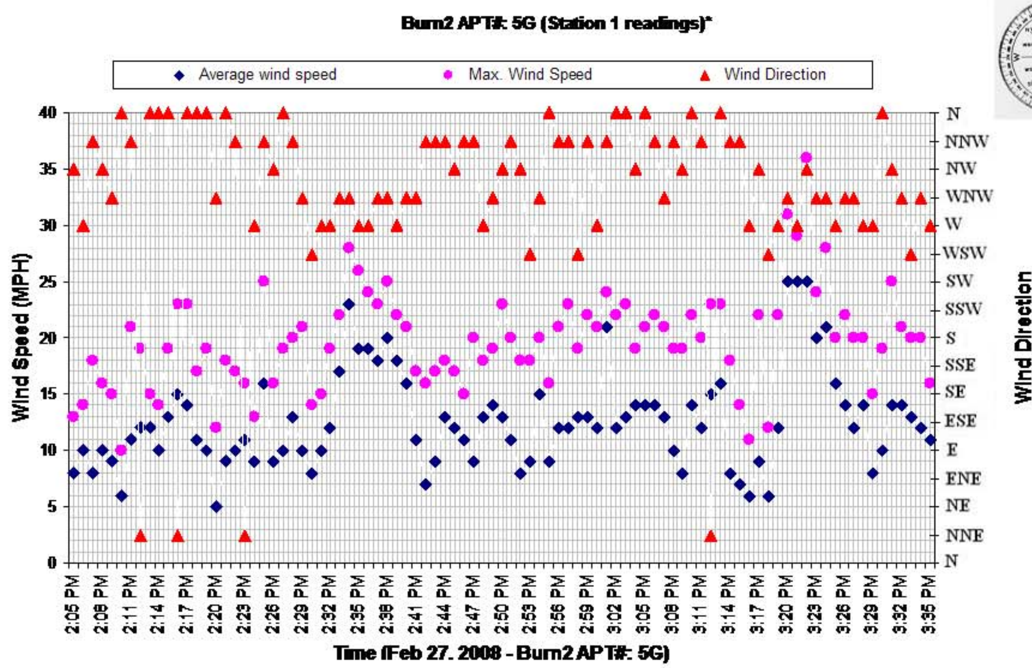


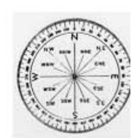

* Station 6 was located on the living room window along longer side of apt#3A

# Day 7 – February 27, 2008

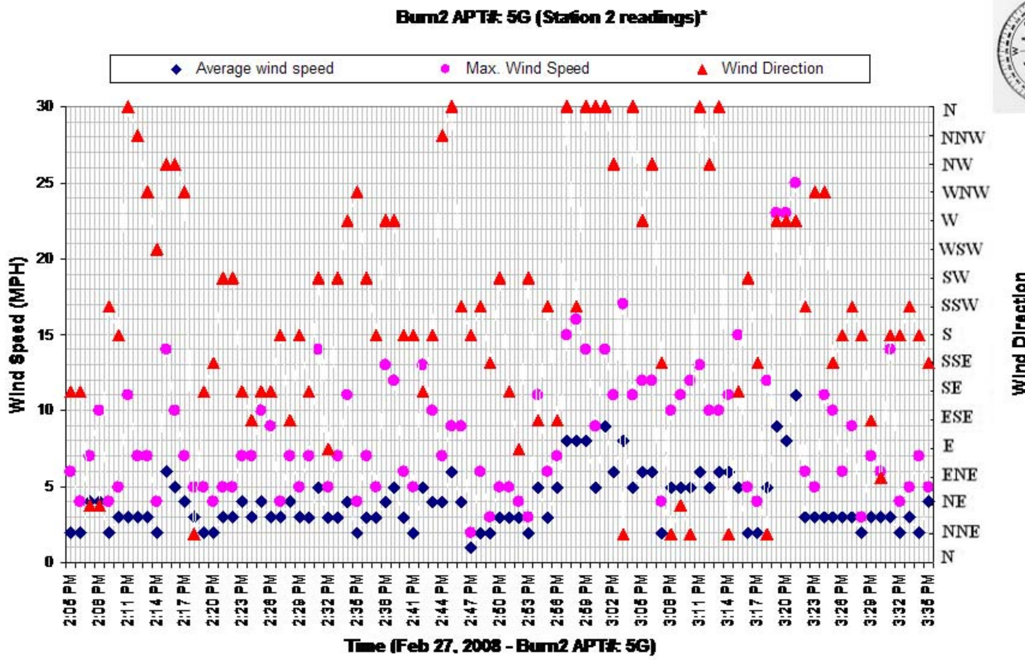
## Second burn in apt # 5G

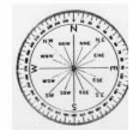




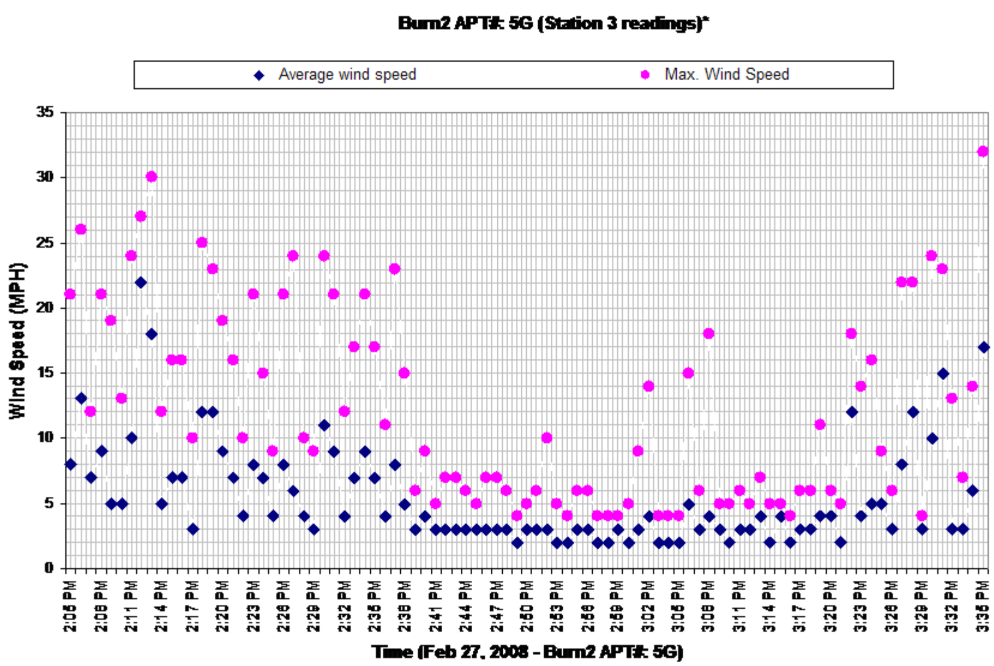



* Station 1 was located on the roof of building #844 : A – F wing

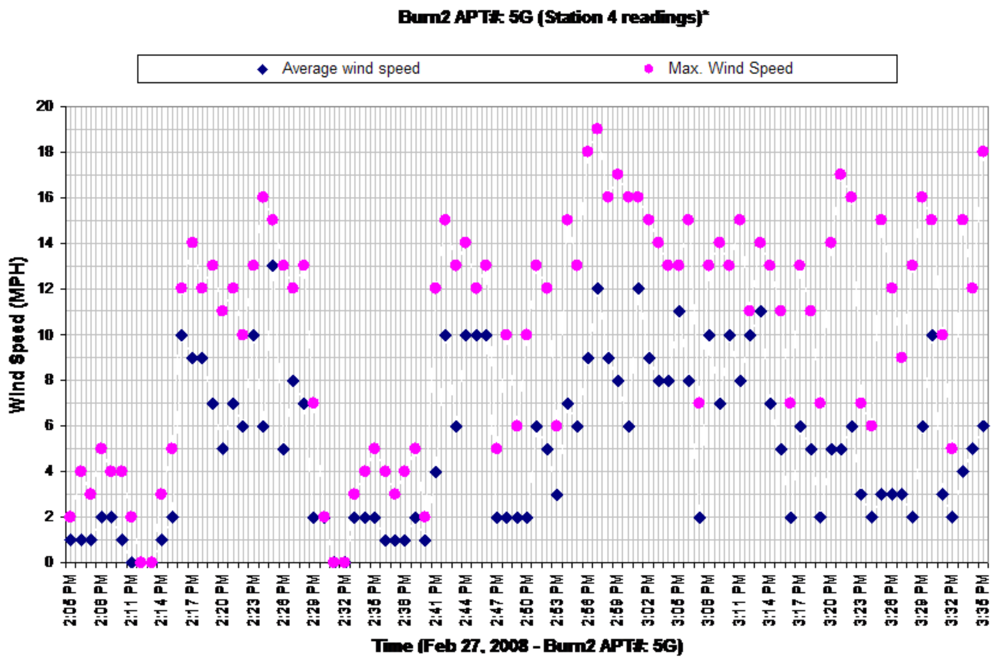


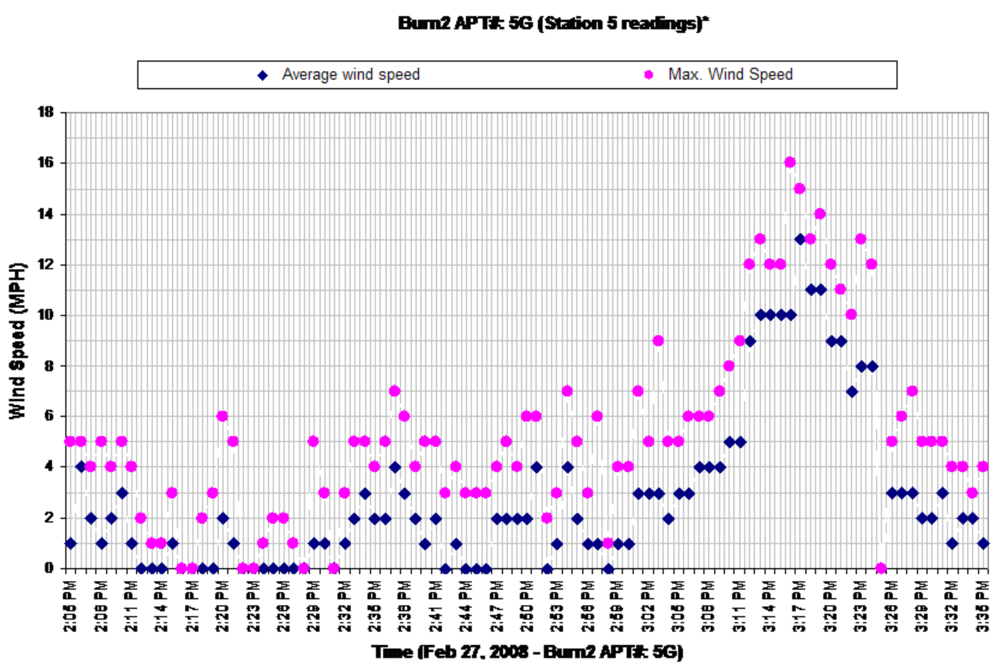
* Station 2 was located on the roof of building #844 : G – L wing



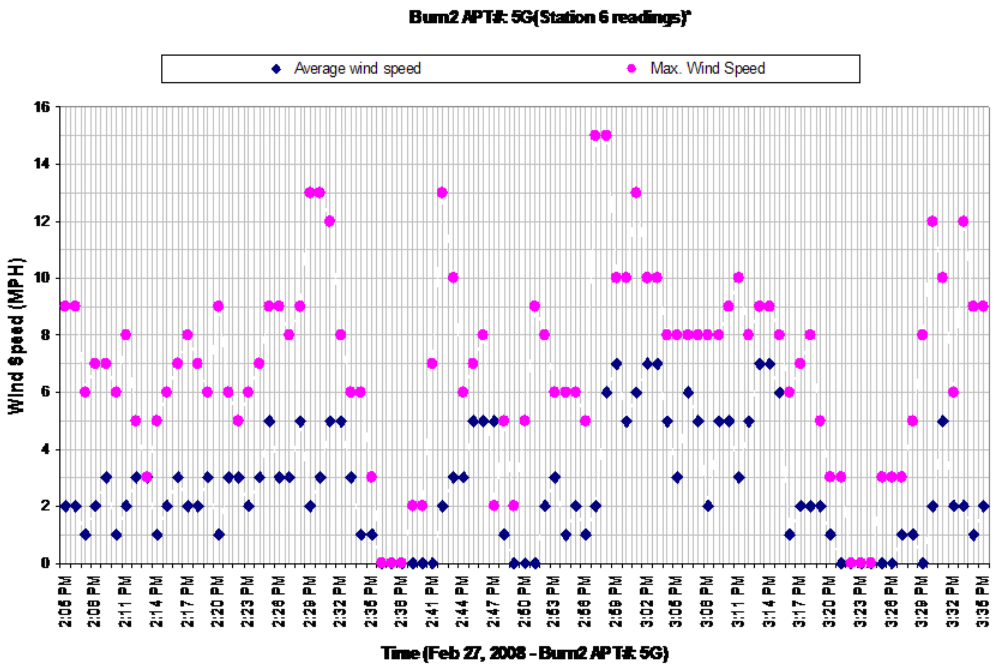

* Station 3 was located on the living room window along longer side of apt#7G




* Station 4 was located on the corner bedroom window along shorter side of apt#7G




* Station 5 was located on the corner bedroom window along shorter side of apt#3G




* Station 6 was located on the living room window of longer side of apt#3G

# Day 8 – February 28, 2008

•Two burn tests were executed.

•First burn test was conducted in apt # 3E and 3A. Second burn test was conducted in apt # 3G to # 3K.

•In all, six weather stations were located at different position around the building # 844 and measuring wind speed and wind directions at respective locations.

•Weather station 1 and weather station 2 were located on the roof of building and measuring external weather conditions

•Weather stations 3, 4, 5 and 6 were located along the wall of building # 844 and measuring the wind speed in vertical plane along the wall.

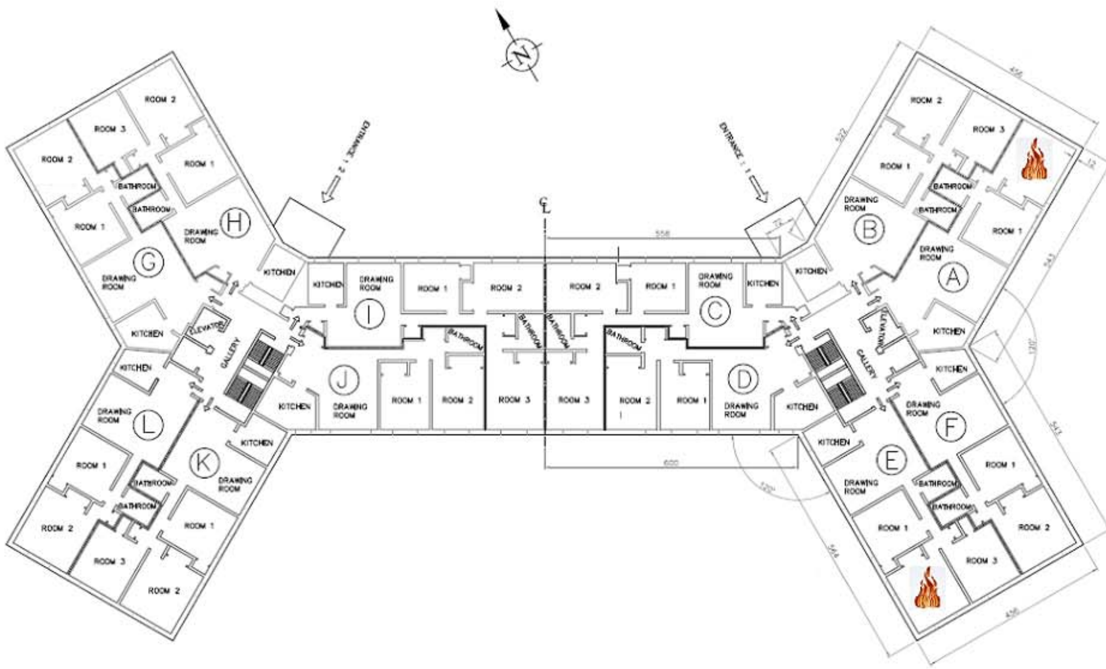
# Day 8 – February 28, 2008

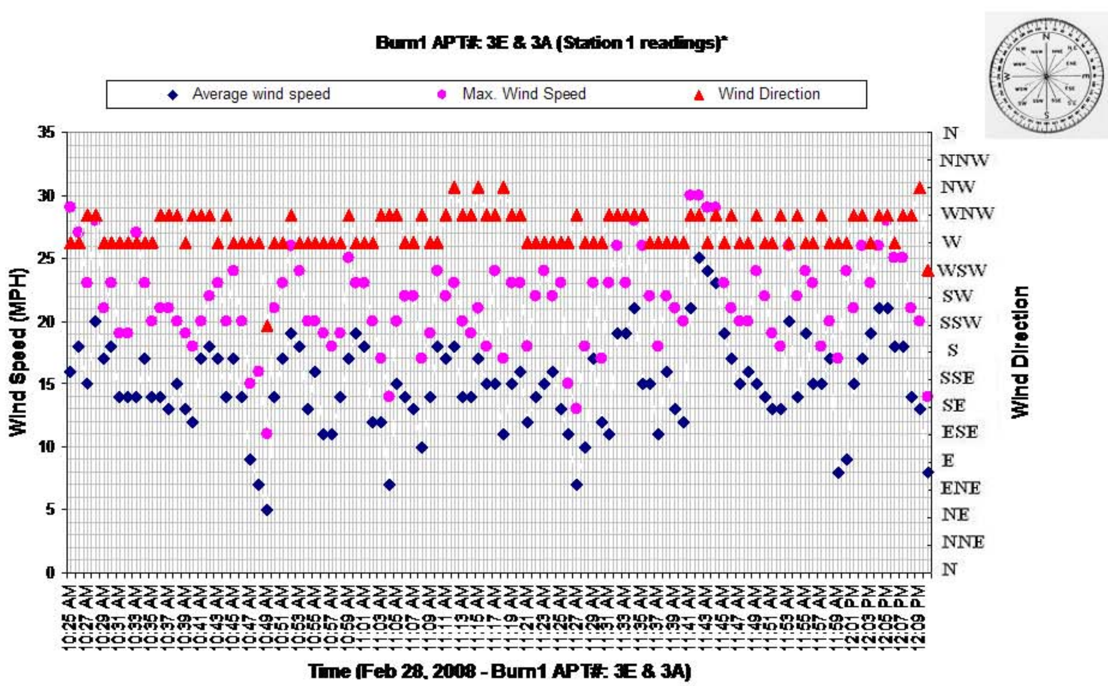
•Readings taken for wind speed, wind direction from respective weather stations for every minute during the period of test have been plotted in following graphs:

•Please note that the specific locations of every weather station has been mentioned at the bottom of respective graph.

# Day 8 – February 28, 2008

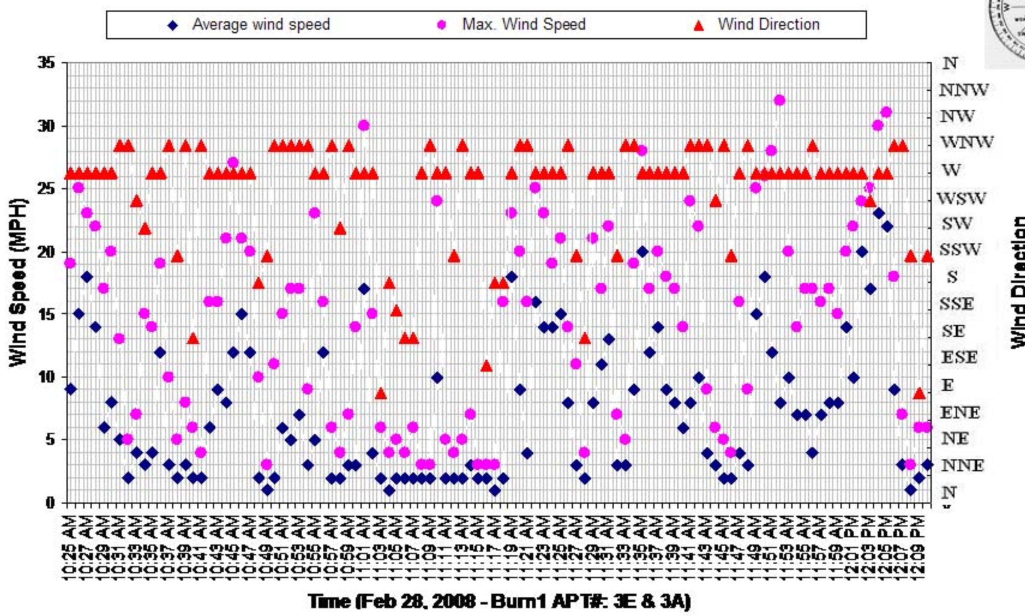
## First burn in apt # 3E & 3A



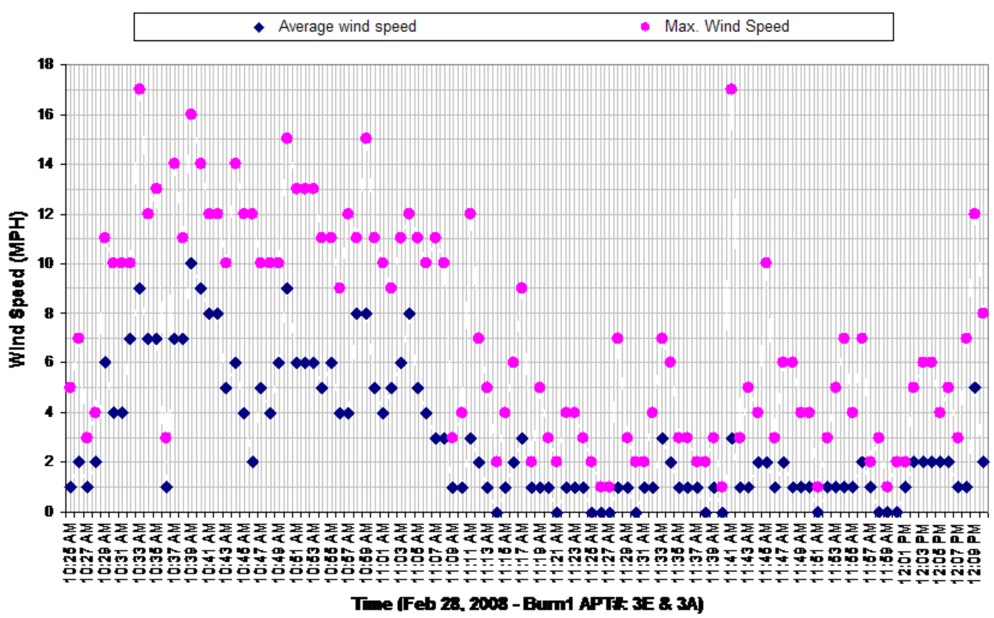

* Station 1 was located on the roof of building #844 : A – F wing

**Burn1 APT#: 3E & 3A (Station 2 readings)***

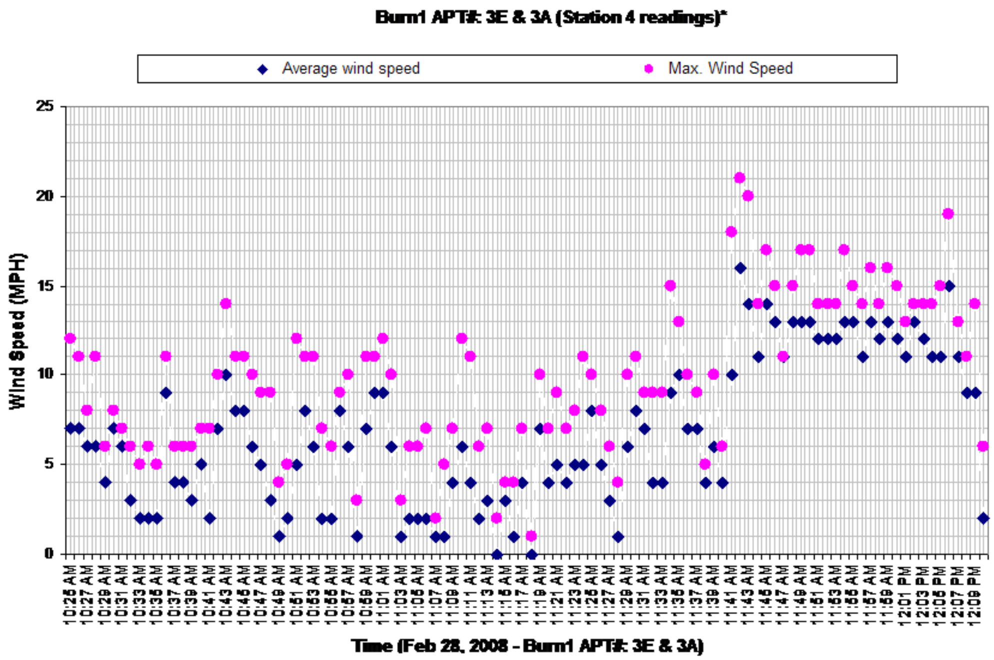



* Station 2 was located on the roof of building #844 : G - L wing

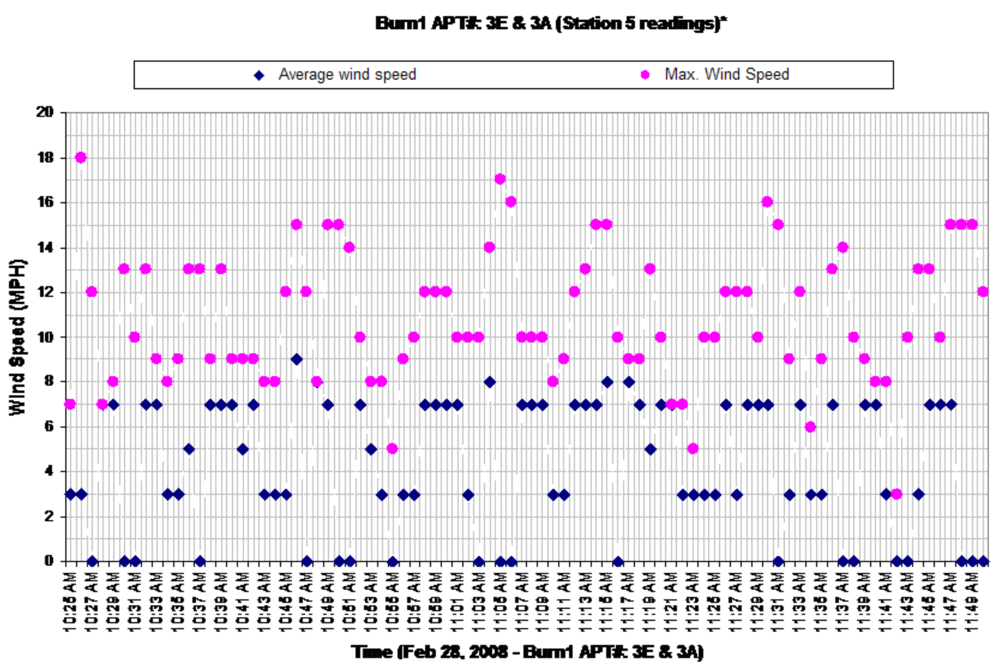
**Burn1 APT#: 3E & 3A (Station 3 readings)***



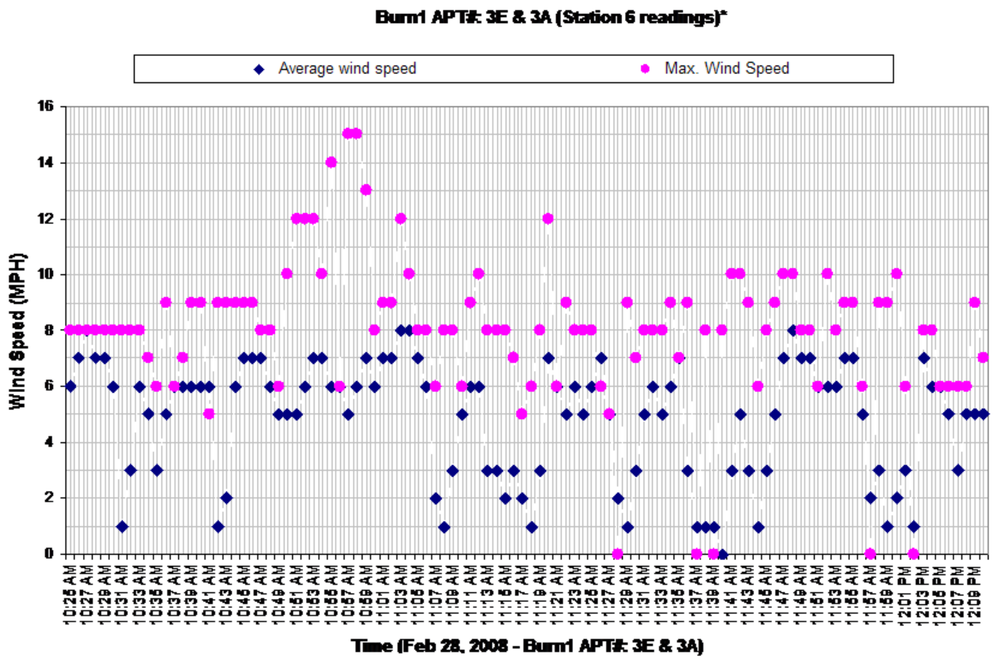

* Station 3 was located on the corner bedroom window along shorter side of apt#5E




* Station 4 was located on the corner bedroom window along shorter side of apt#5A



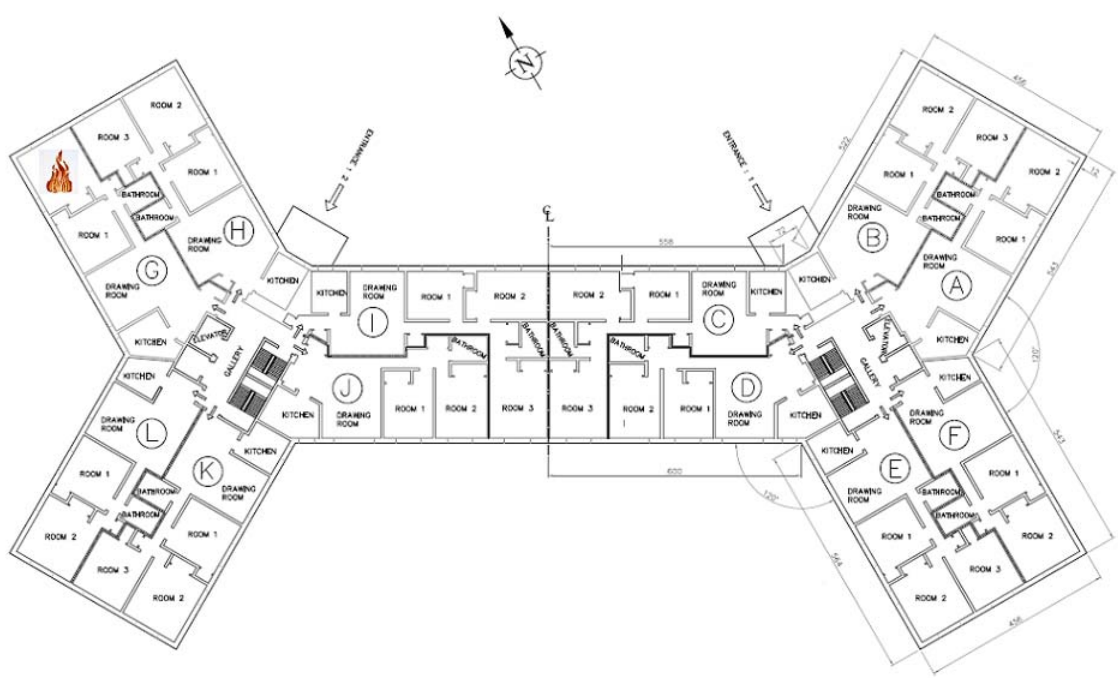

* Station 5 was located on the living room window along longer side of apt#5A

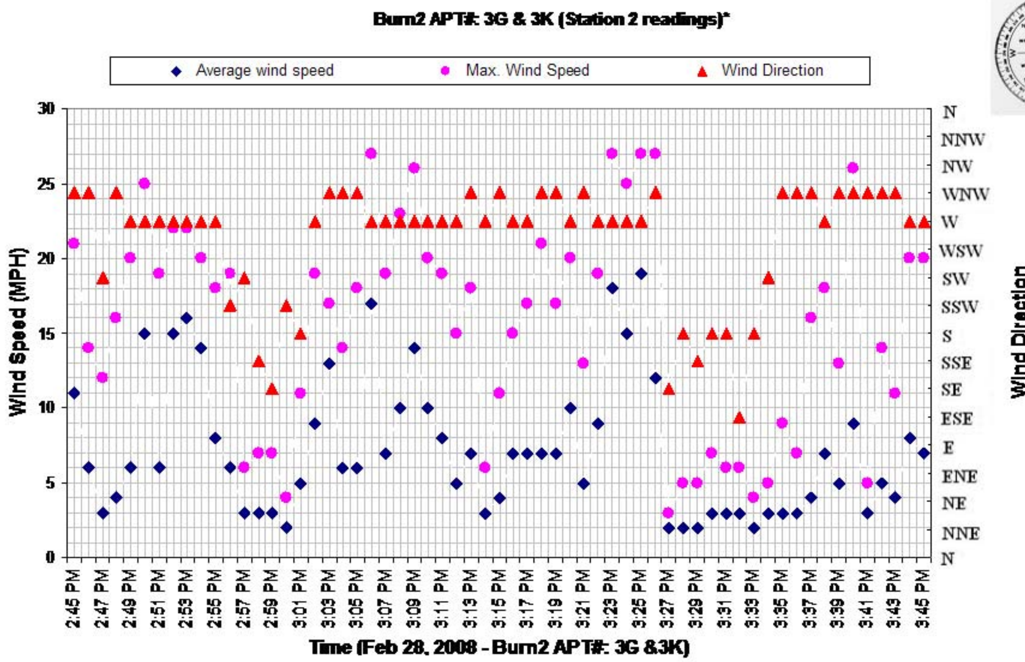



* Station 6 was located on the living room window along longer side of apt#5E

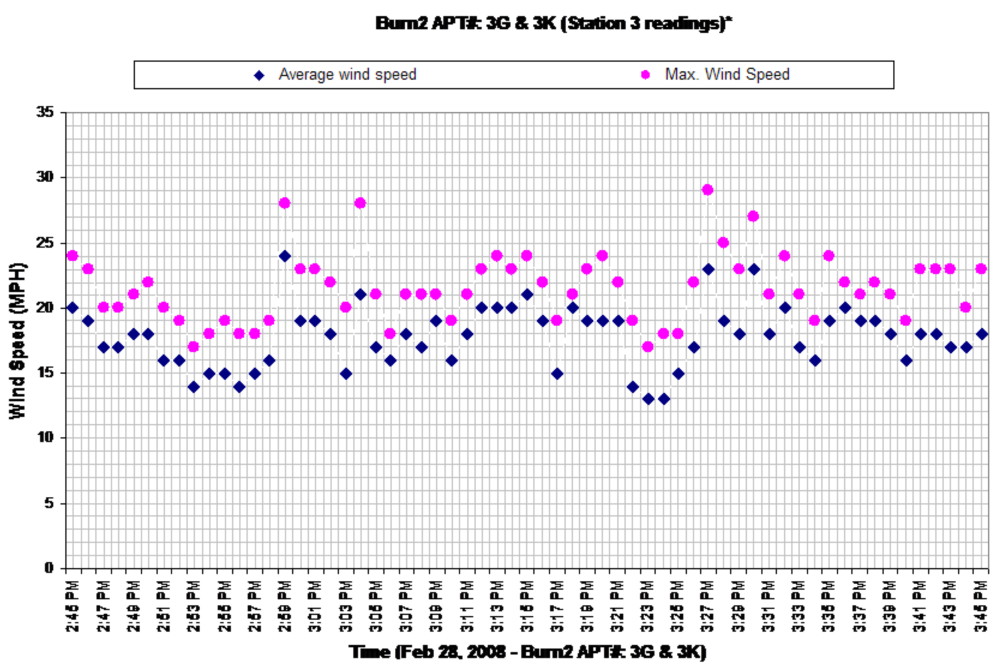
# Day 8 – February 28, 2008

## Second burn in apt # 3G to 3K

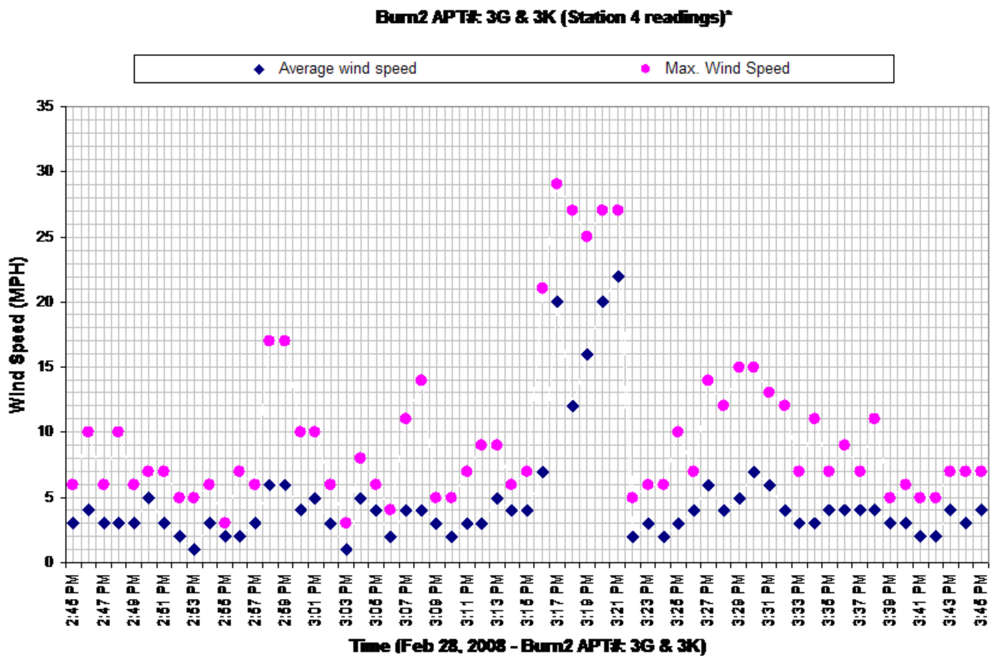




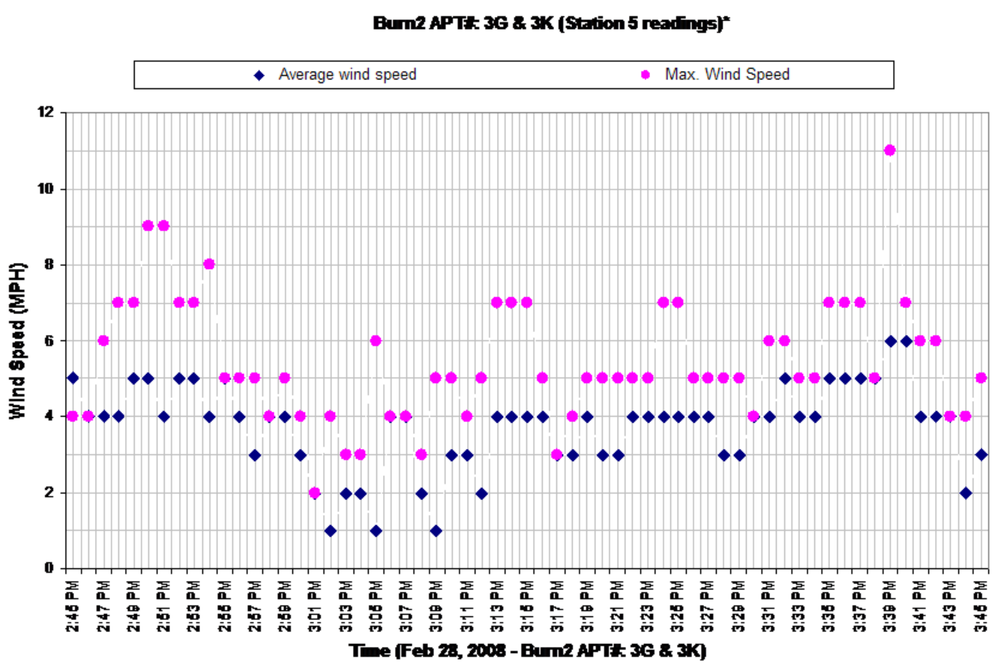

* Station 2 was located on the roof of building #844 : G – L wing




* Station 3 was located on the corner bedroom window along shorter side of apt#5K

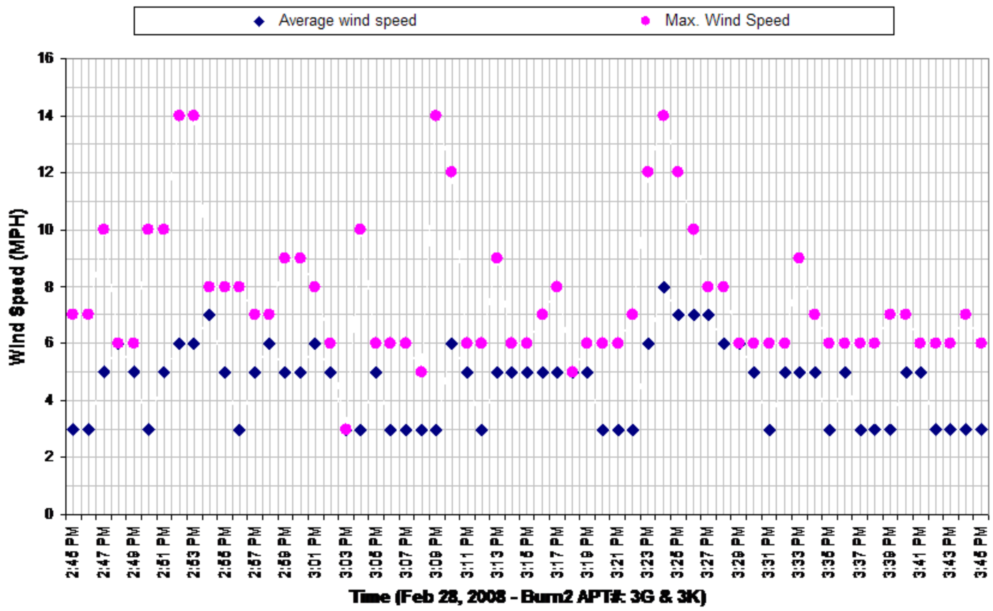



* Station 4 was located on the corner bedroom window along shorter side of apt#5G




* Station 5 was located on the living room window along longer side of apt#5G

**Burn2 APT#: 3G & 3K (Station 6 readings)***




* Station 6 was located on the living room window along longer side of apt#5K

## 9.4 Appendix D – Detailed Graphs

### 9.4.1 Experiment 7G

#### 9.4.1.1 Temperatures

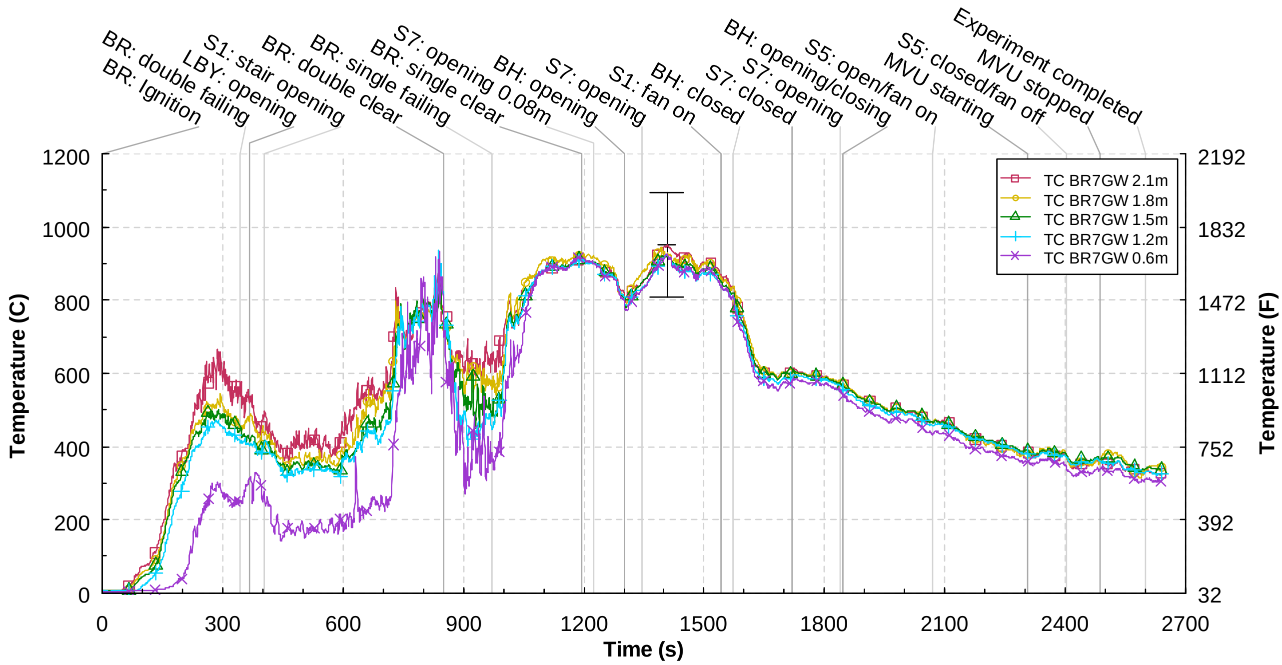



**Figure 9.4-1. Temperature versus time for the 7G bedroom thermocouple tree, Experiment 7G**

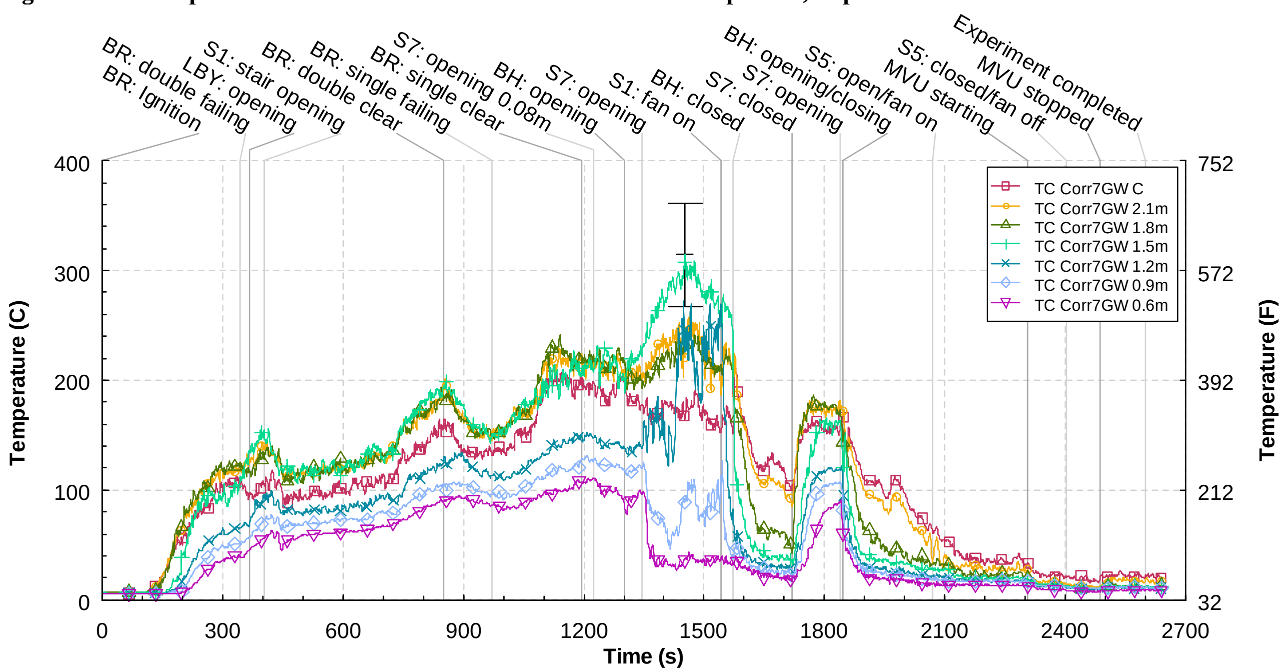



**Figure 9.4-2. Temperature versus time for the 7G hall thermocouple tree, Experiment 7G**

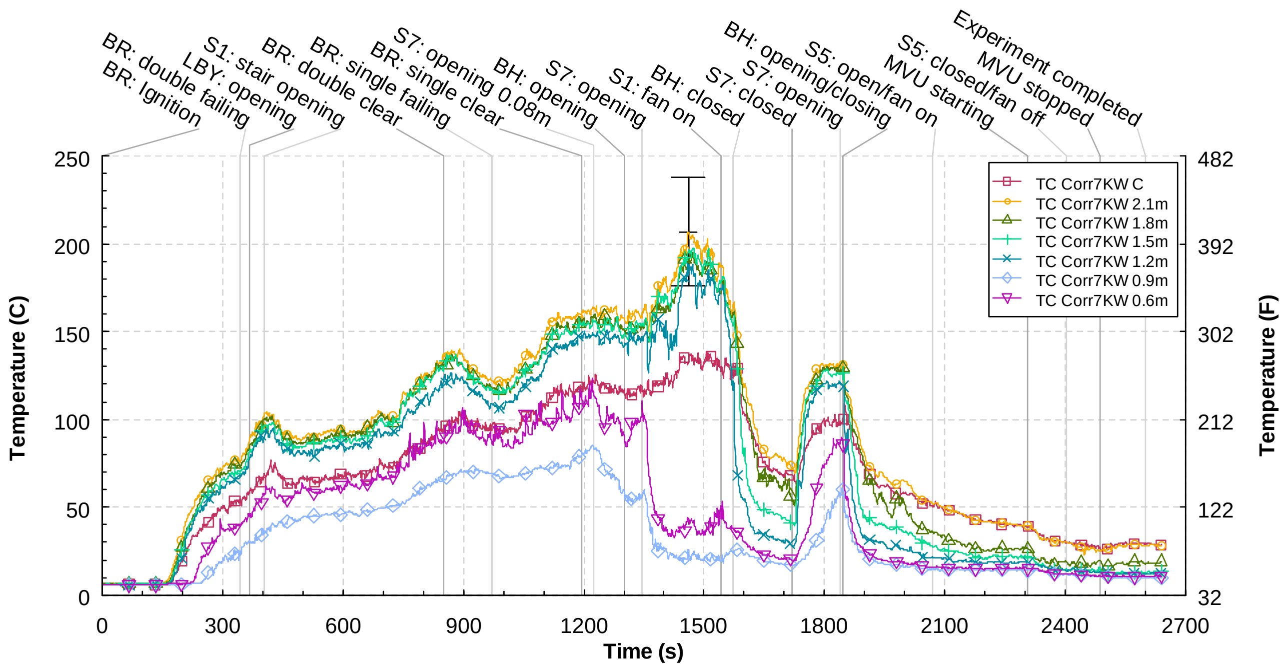



**Figure 9.4-3. Temperature versus time for the 7K hall thermocouple tree, Experiment 7G**

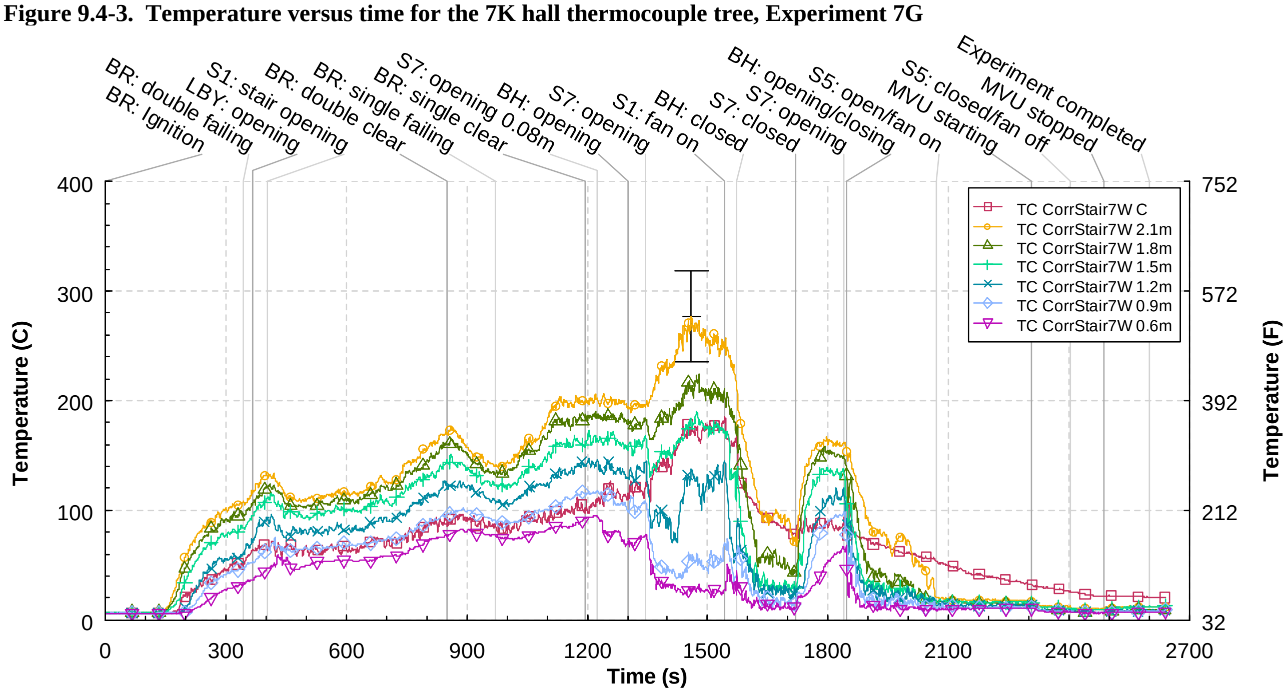



**Figure 9.4-4. Temperature versus time for the 7th floor stair hall thermocouple tree, Experiment 7G**

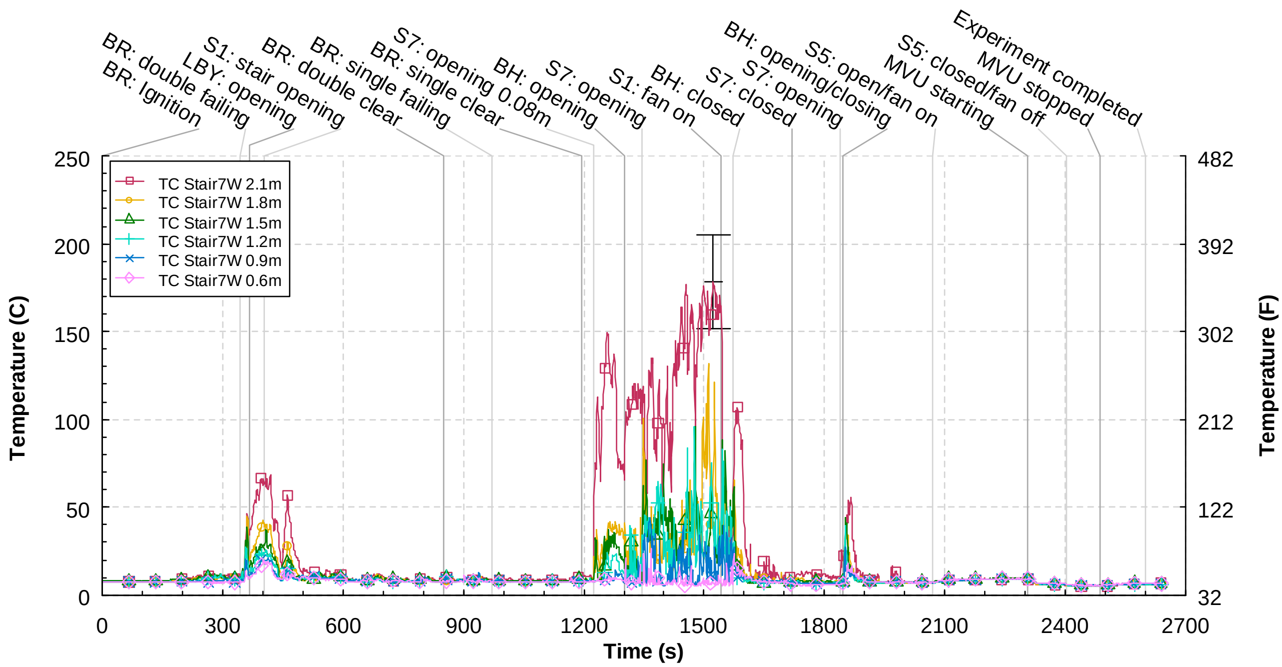



**Figure 9.4-5. Temperature versus time for the 7th floor stairwell thermocouple tree, Experiment 7G**

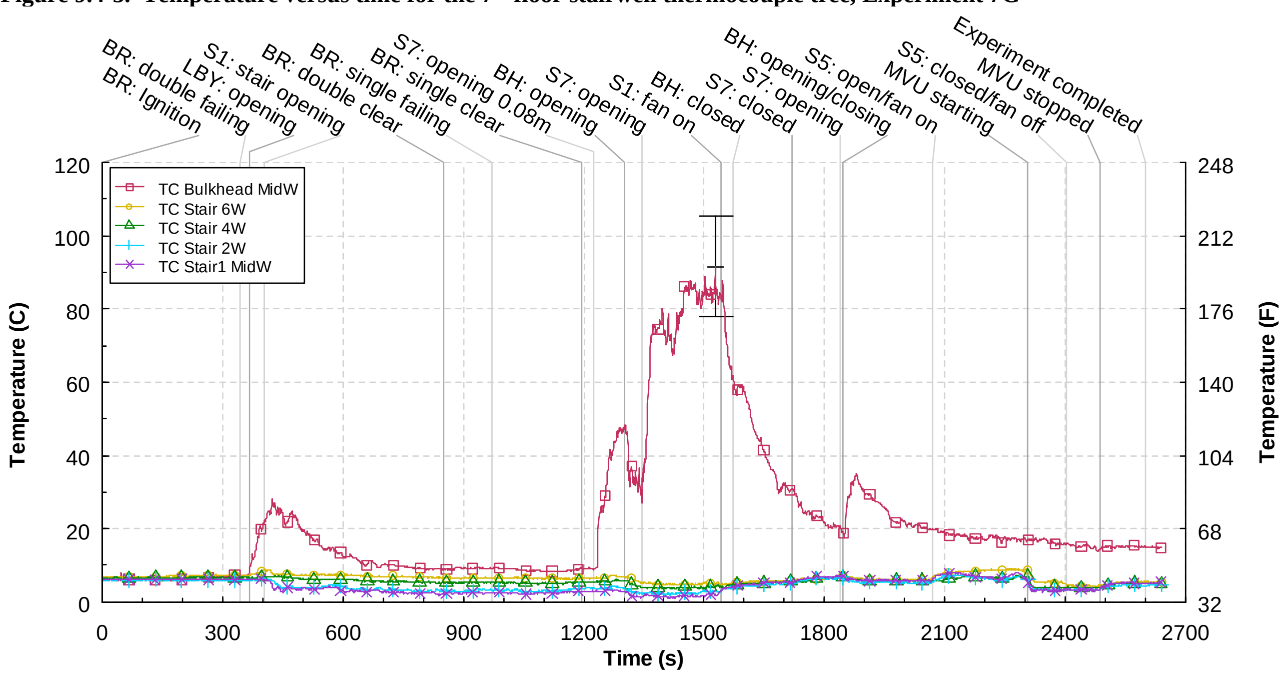



**Figure 9.4-6. Temperature versus time for the stair thermocouples, Experiment 7G**

### 9.4.1.2 Pressures

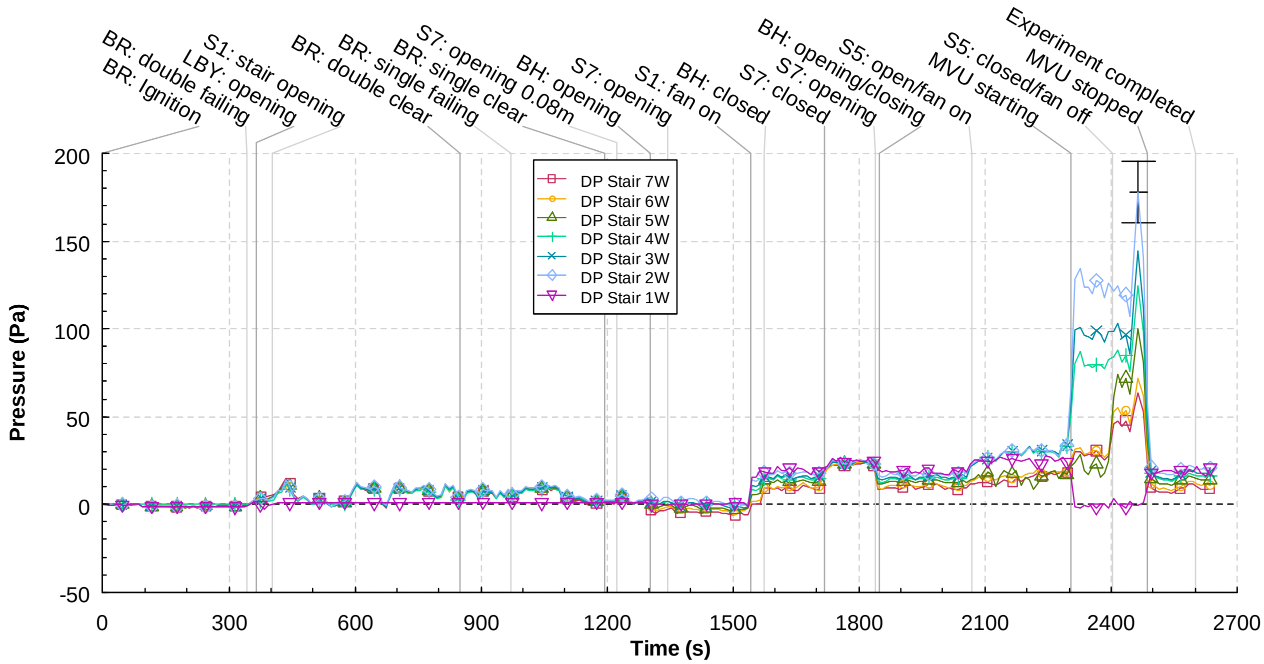



**Figure 9.4-7. Differential pressure versus time for the stairwell bi-directional probes, Experiment 7G**

### 9.4.1.3 Velocities

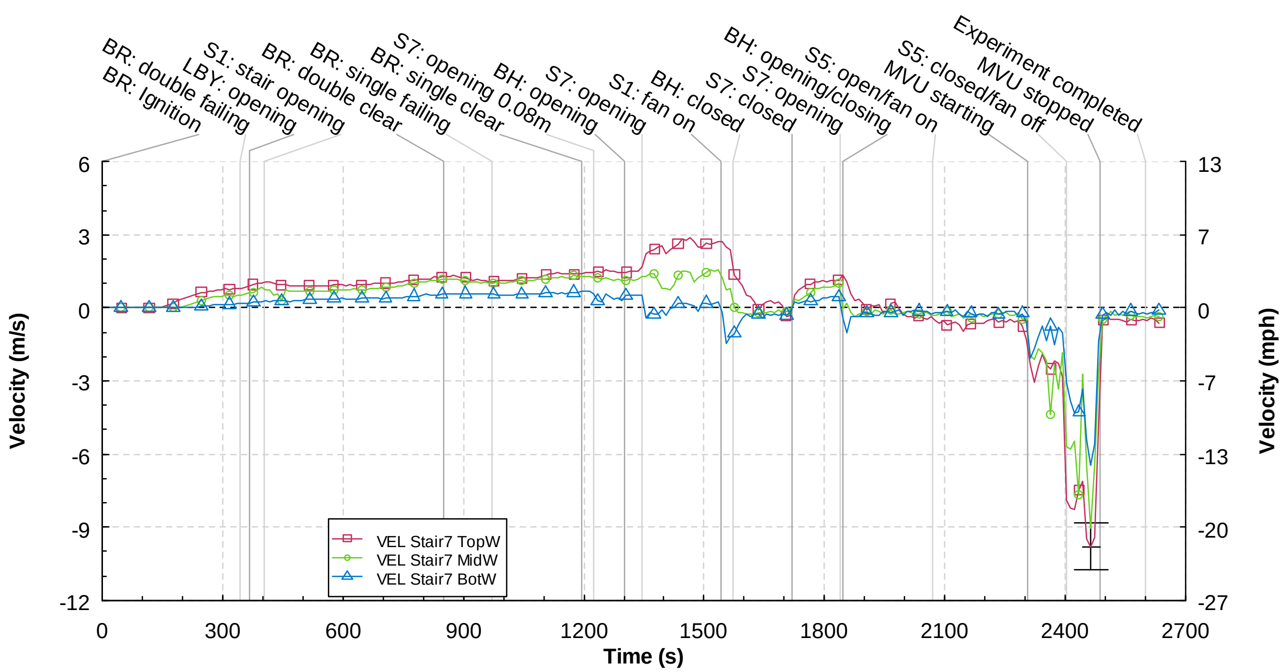



**Figure 9.4-8. Velocity versus time for the 7th floor stairwell bi-directional probes, Experiment 7G**

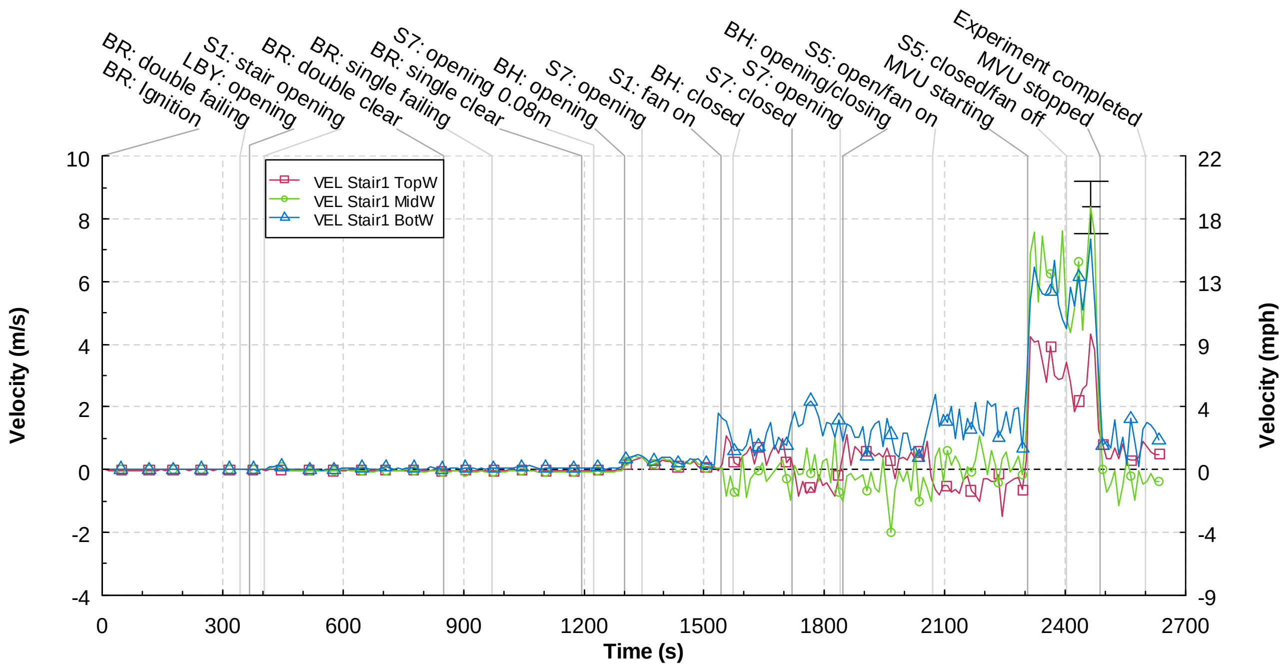



**Figure 9.4-9. Velocity versus time for the 1st floor stairwell bi-directional probes, Experiment 7G**

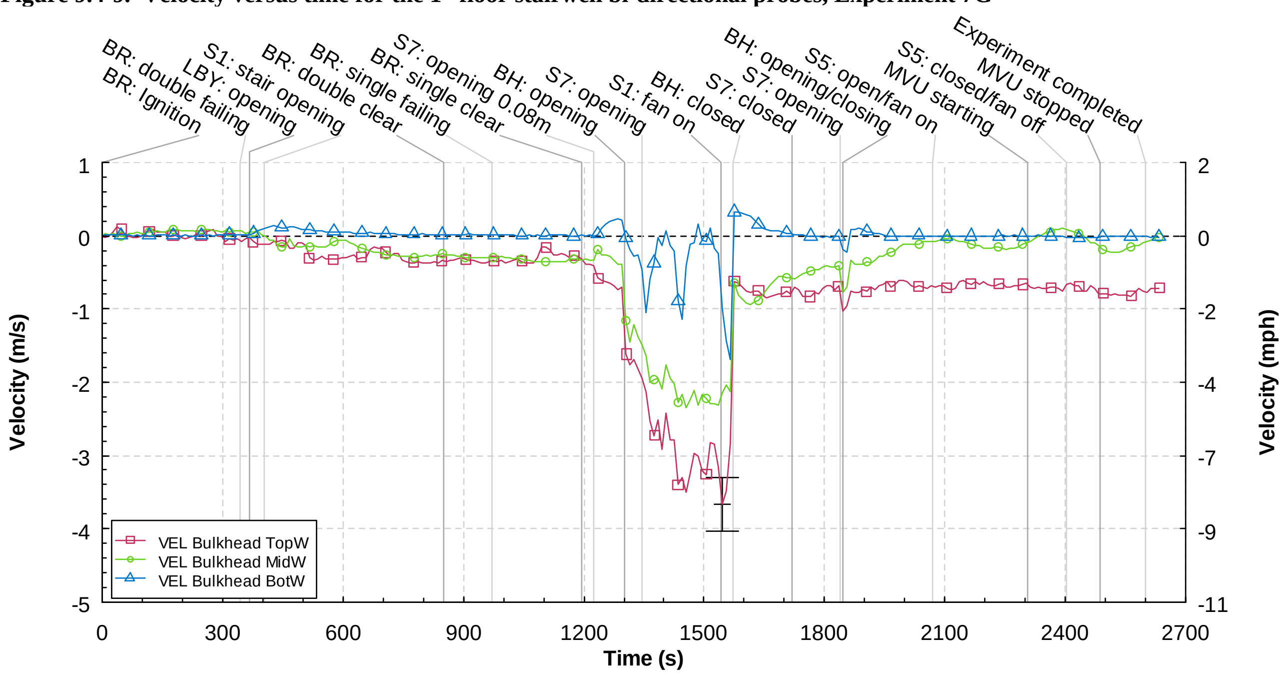



**Figure 9.4-10. Velocity versus time for the bulkhead bi-directional probes, Experiment 7G**

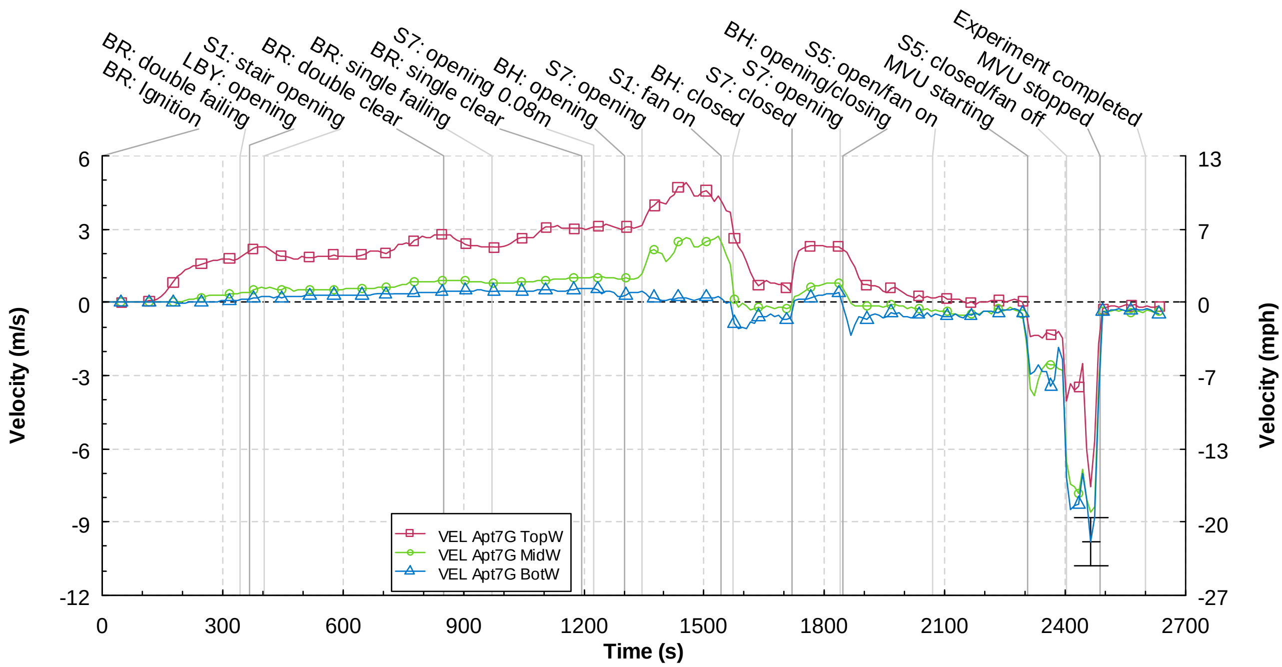



**Figure 9.4-11. Velocity versus time for the apartment 7G doorway bi-directional probes, Experiment 7G**

## 9.4.2 Experiment 7G2

### 9.4.2.1 Temperatures

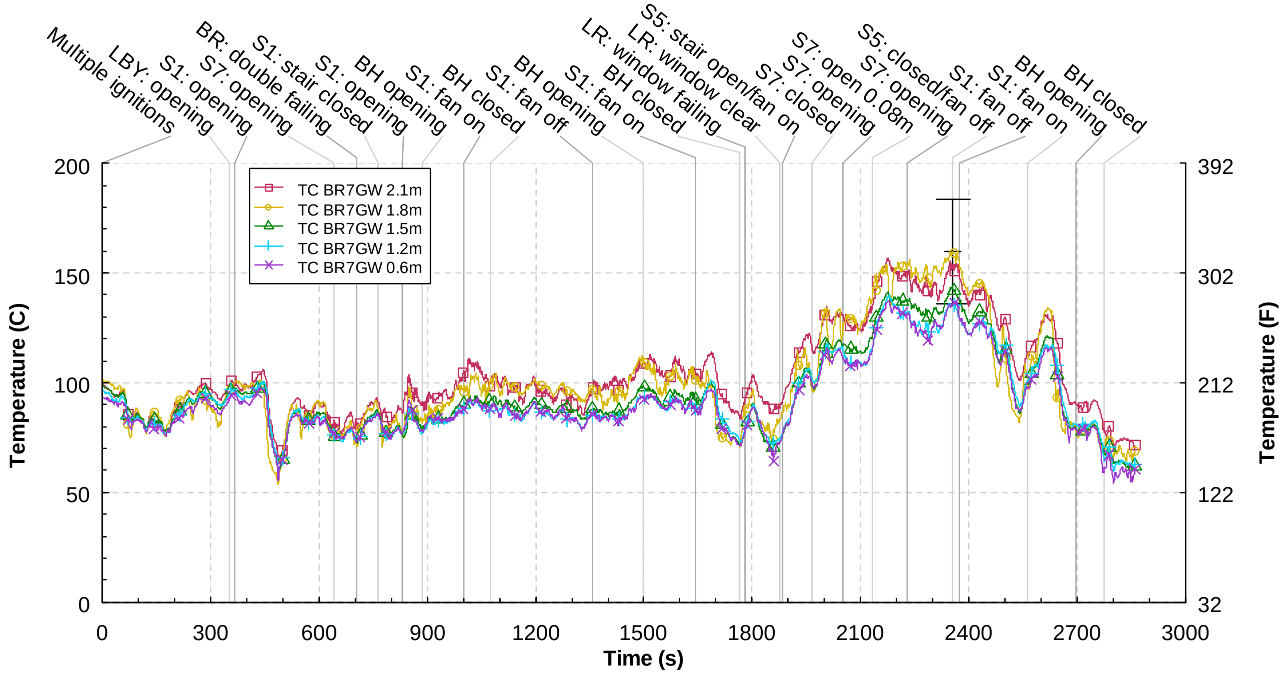



**Figure 9.4-12. Temperature versus time for the 7G2 bedroom thermocouple tree, Experiment 7G2**

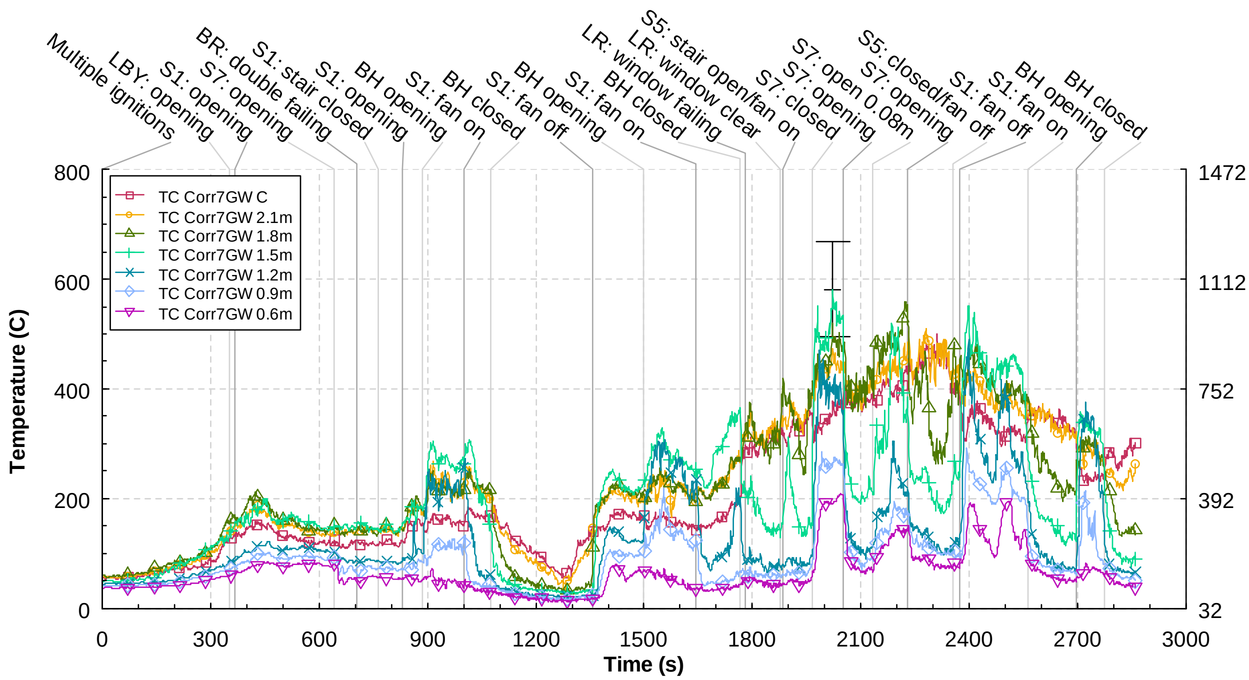



**Figure 9.4-13. Temperature versus time for the 7G2 hall thermocouple tree, Experiment 7G2**

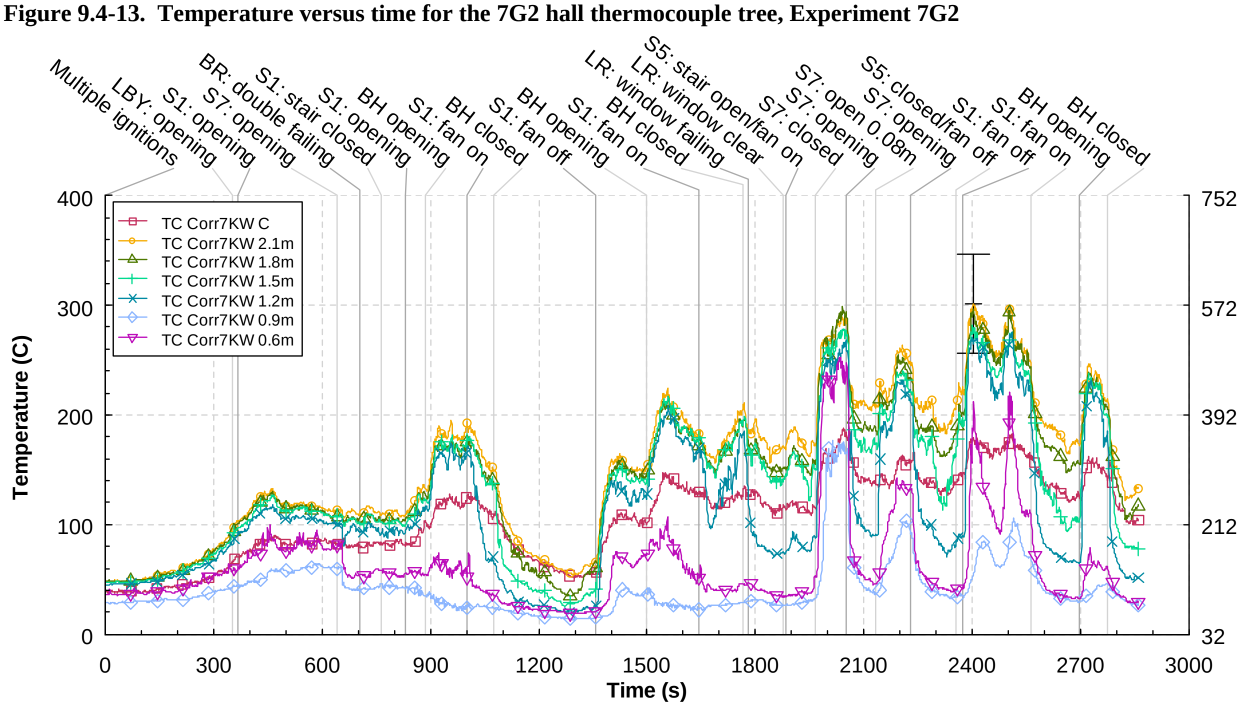



**Figure 9.4-14. Temperature versus time for the 7K hall thermocouple tree, Experiment 7G2**

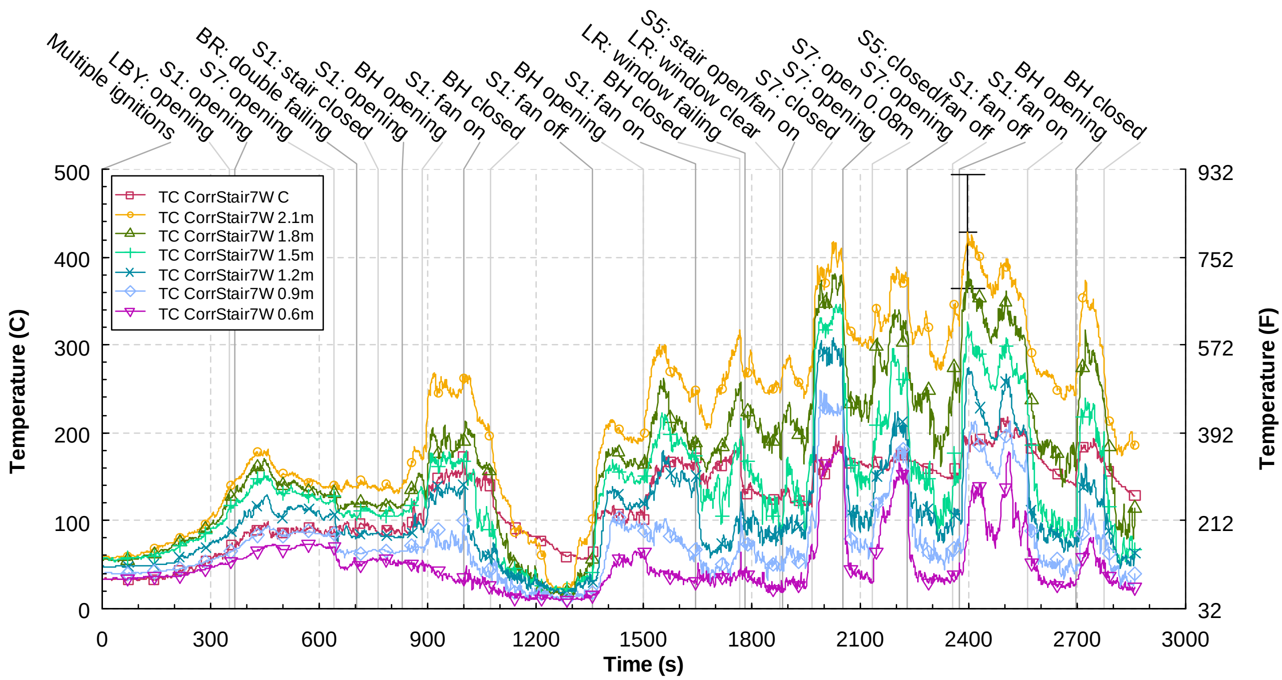



**Figure 9.4-15. Temperature versus time for the 7th floor stair hall thermocouple tree, Experiment 7G2**

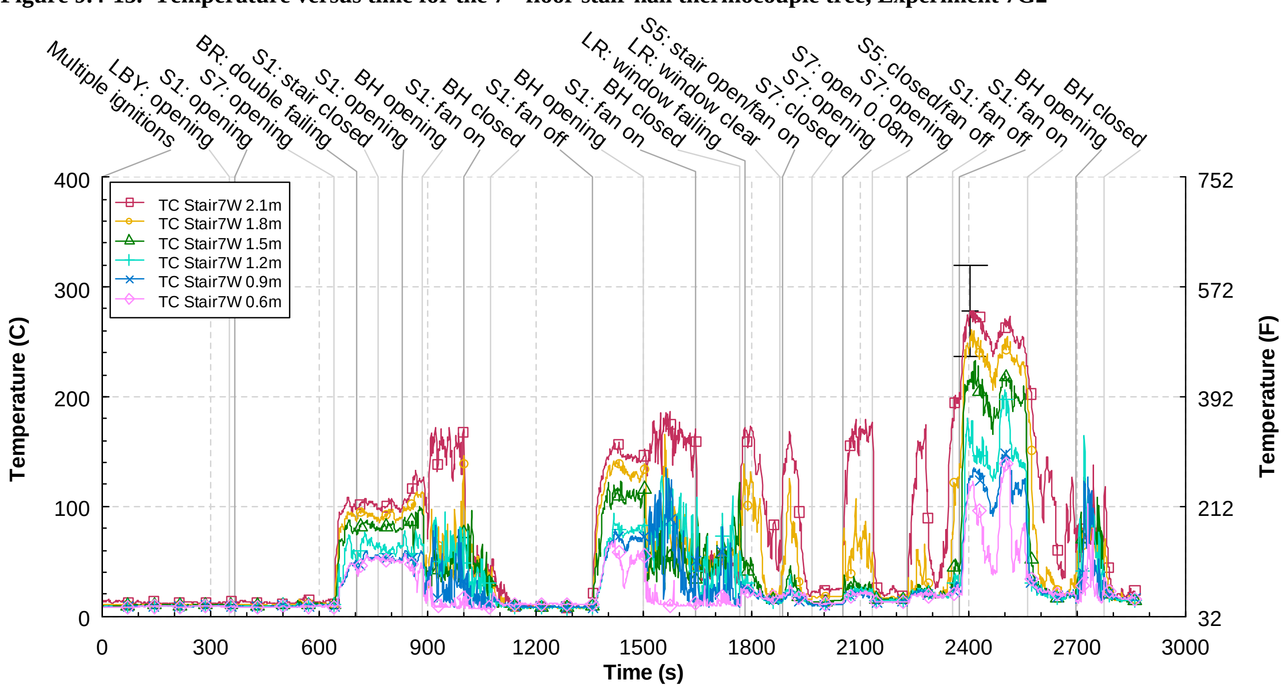



**Figure 9.4-16. Temperature versus time for the 7th floor stairwell thermocouple tree, Experiment 7G2**

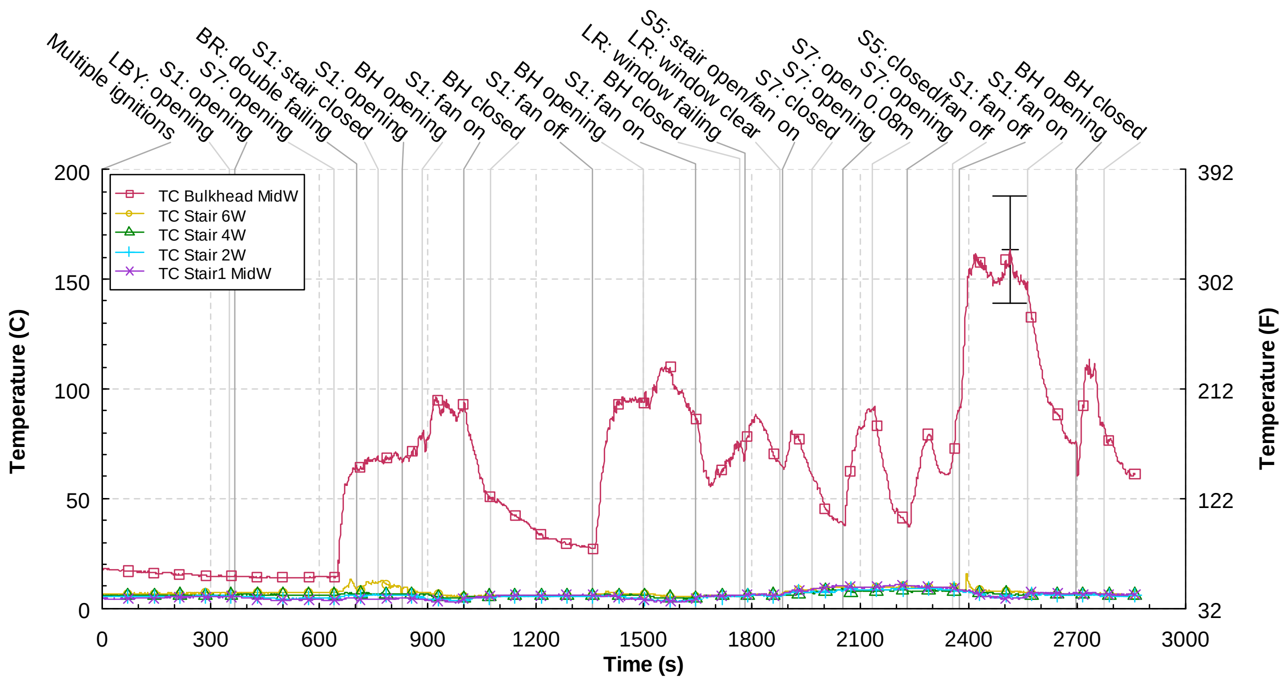



**Figure 9.4-17. Temperature versus time for the stair thermocouples, Experiment 7G2**

## 9.4.2.2 Pressures

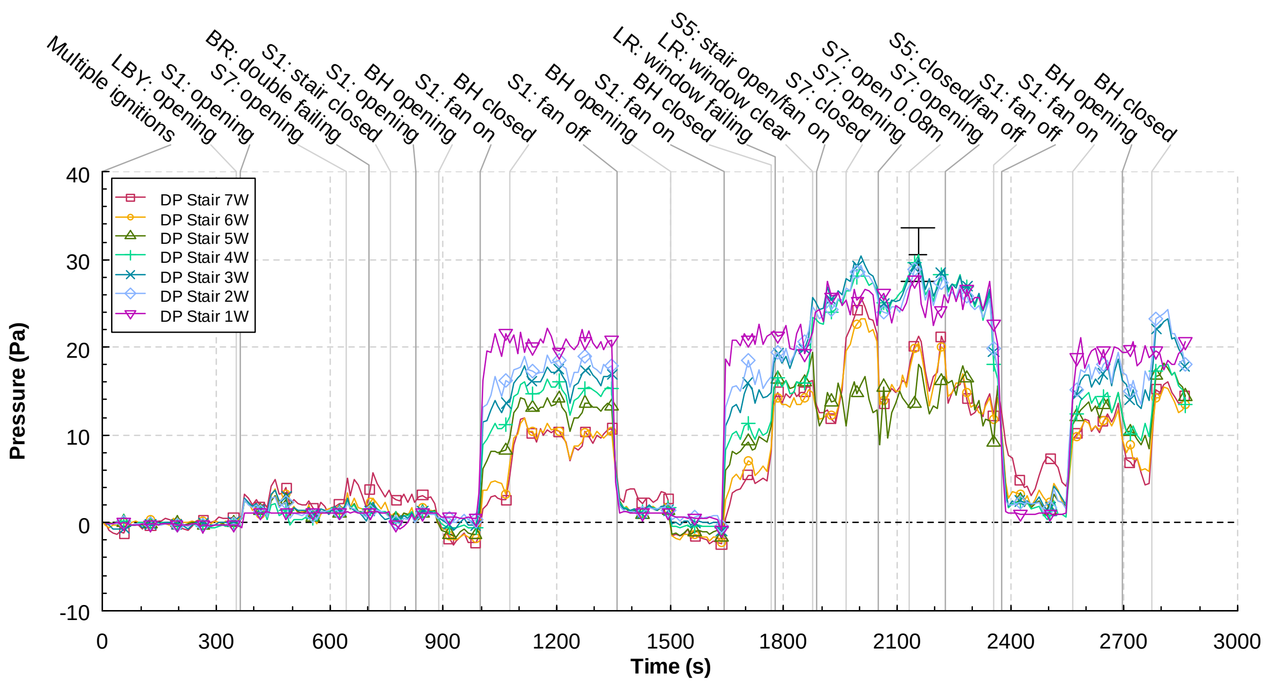



**Figure 9.4-18. Differential pressure versus time for the stairwell bi-directional probes, Experiment 7G2**

### 9.4.2.3 Velocities

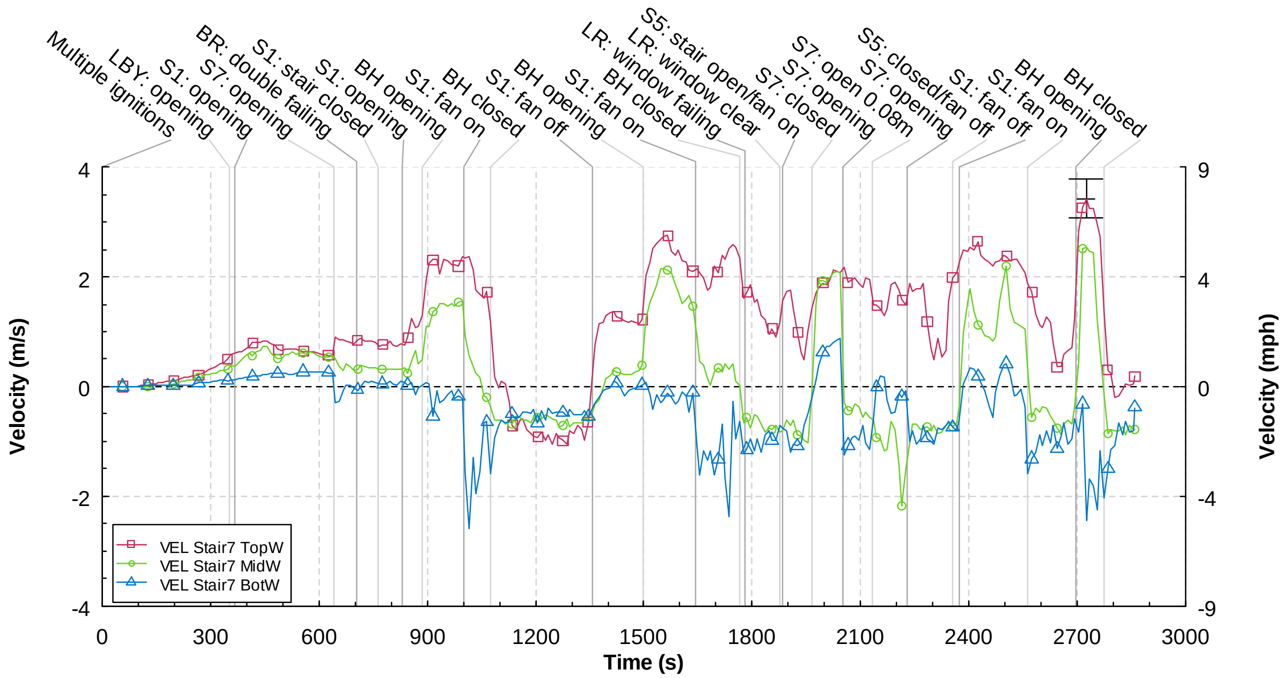



**Figure 9.4-19. Velocity versus time for the 7th floor stairwell bi-directional probes, Experiment 7G2**

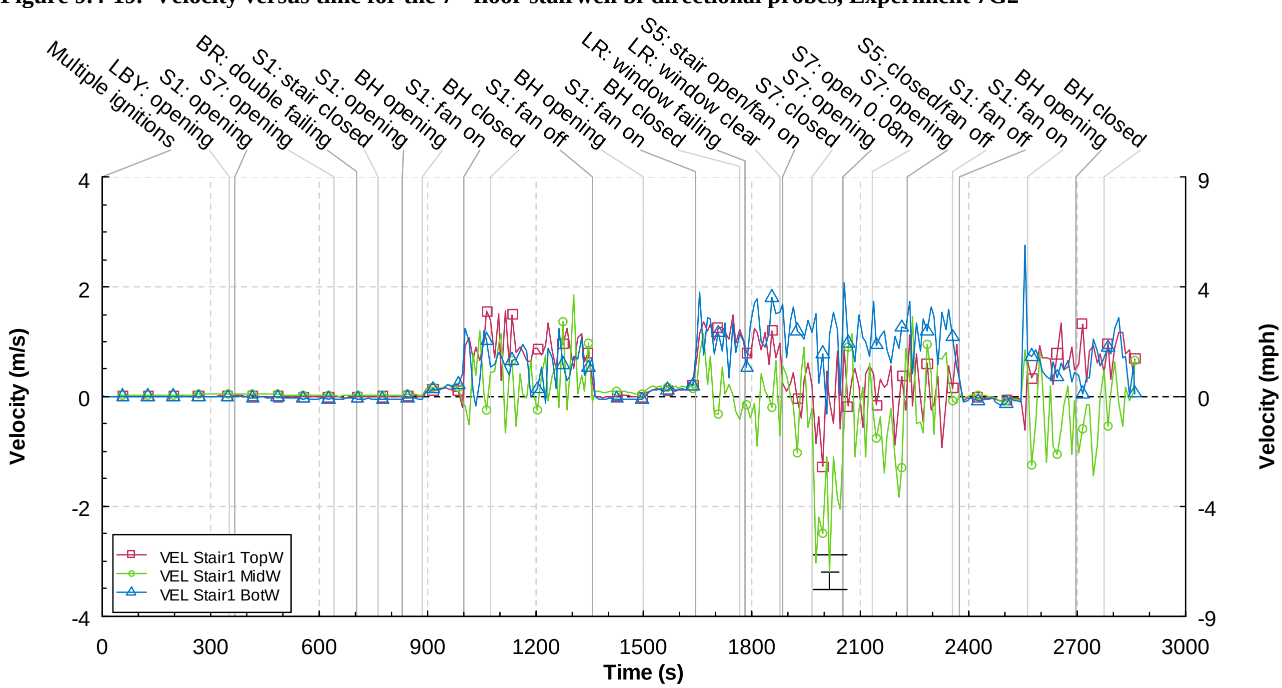



**Figure 9.4-20. Velocity versus time for the 1st floor stairwell bi-directional probes, Experiment 7G2**

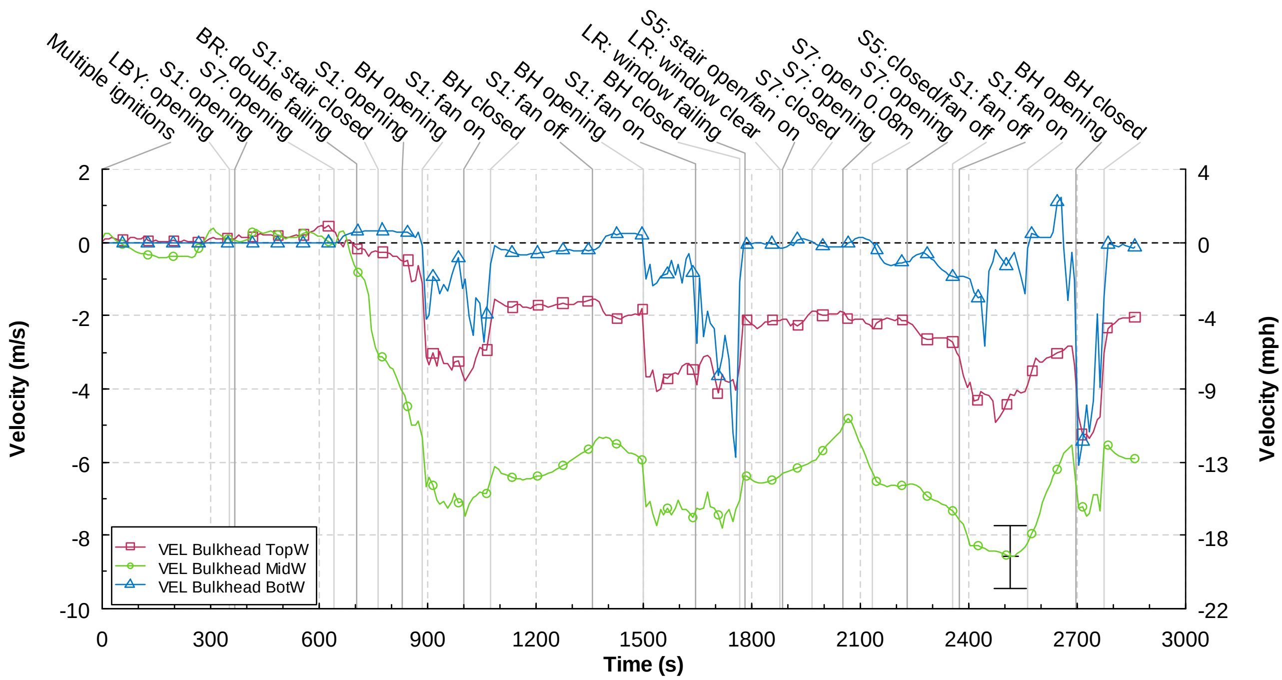



**Figure 9.4-21. Velocity versus time for the bulkhead bi-directional probes, Experiment 7G2**

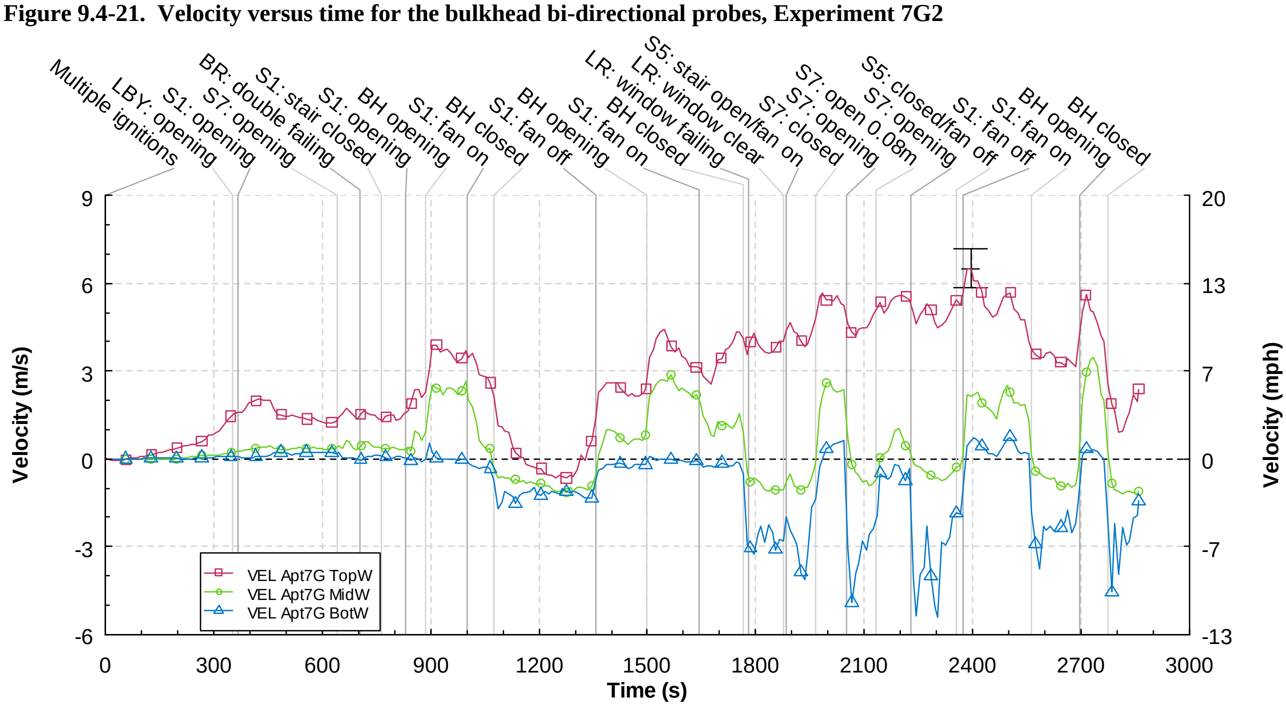



**Figure 9.4-22. Velocity versus time for the apartment 7G doorway bi-directional probes, Experiment 7G2**

### 9.4.3 Experiment 7E

#### 9.4.3.1 Temperatures

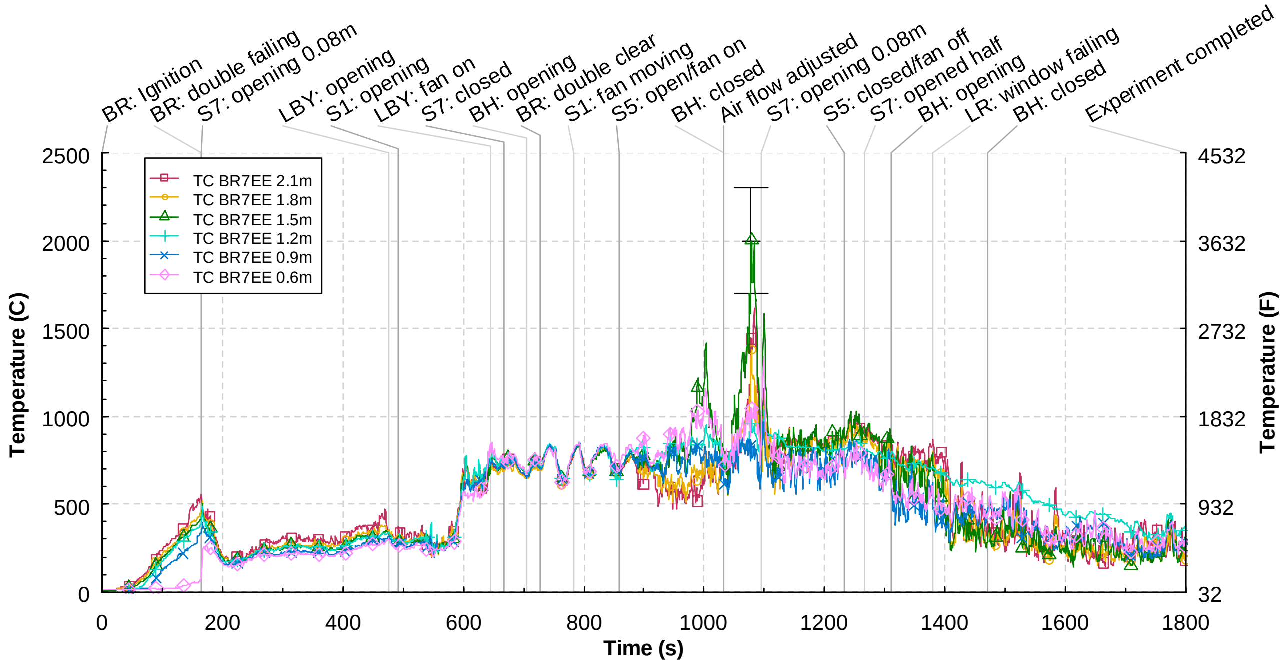



**Figure 9.4-23. Temperature versus time for the 7E bedroom thermocouple tree, Experiment 7E**

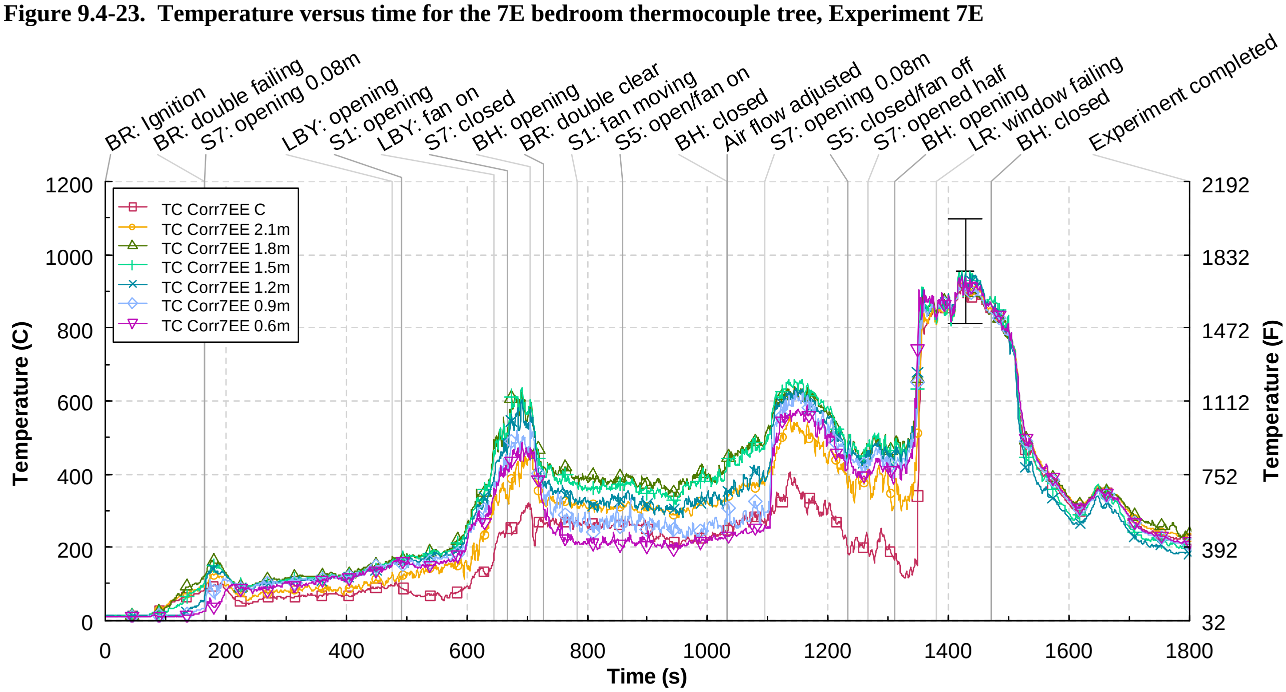



**Figure 9.4-24. Temperature versus time for the 7E hall thermocouple tree, Experiment 7E**

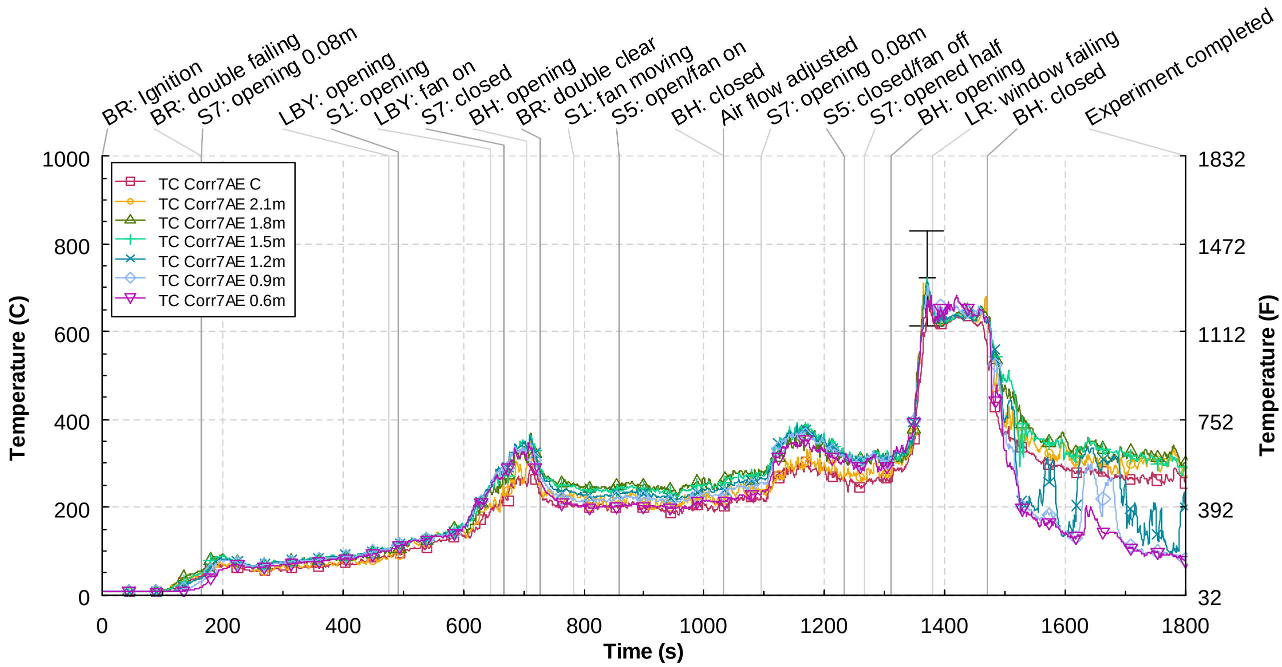



**Figure 9.4-25. Temperature versus time for the 7A hall thermocouple tree, Experiment 7E**

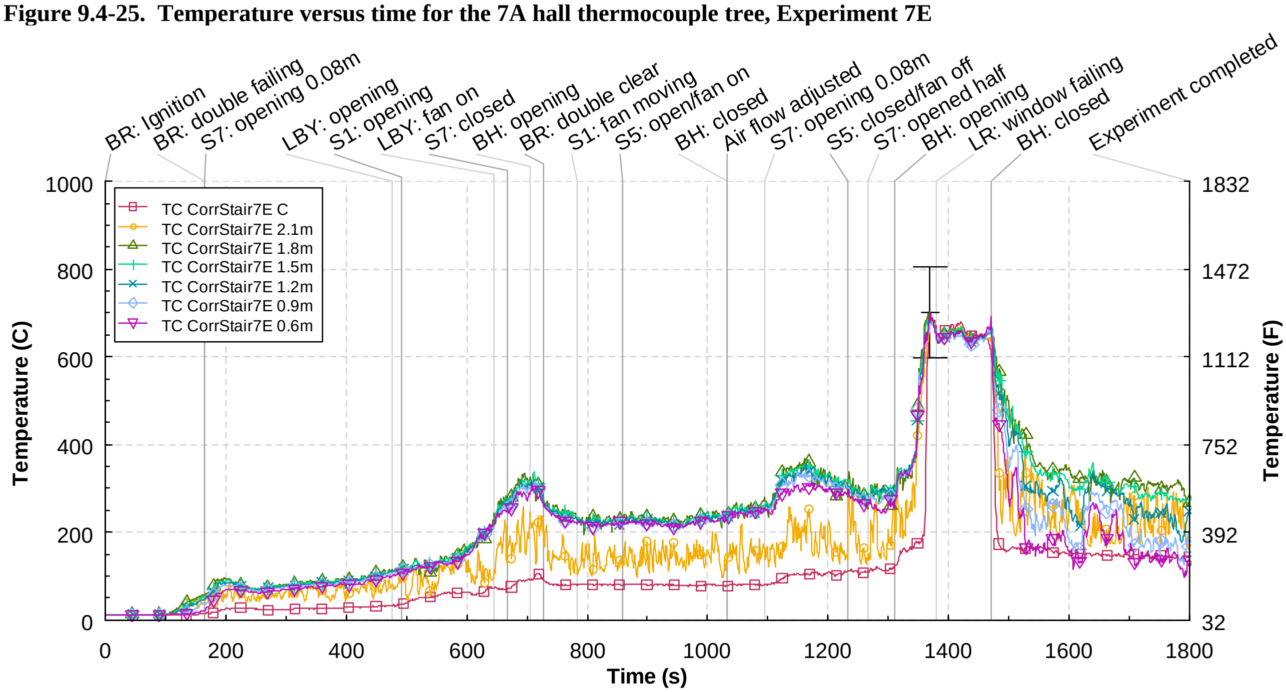



**Figure 9.4-26. Temperature versus time for the 7$^{th}$ floor stair hall thermocouple tree, Experiment 7E**

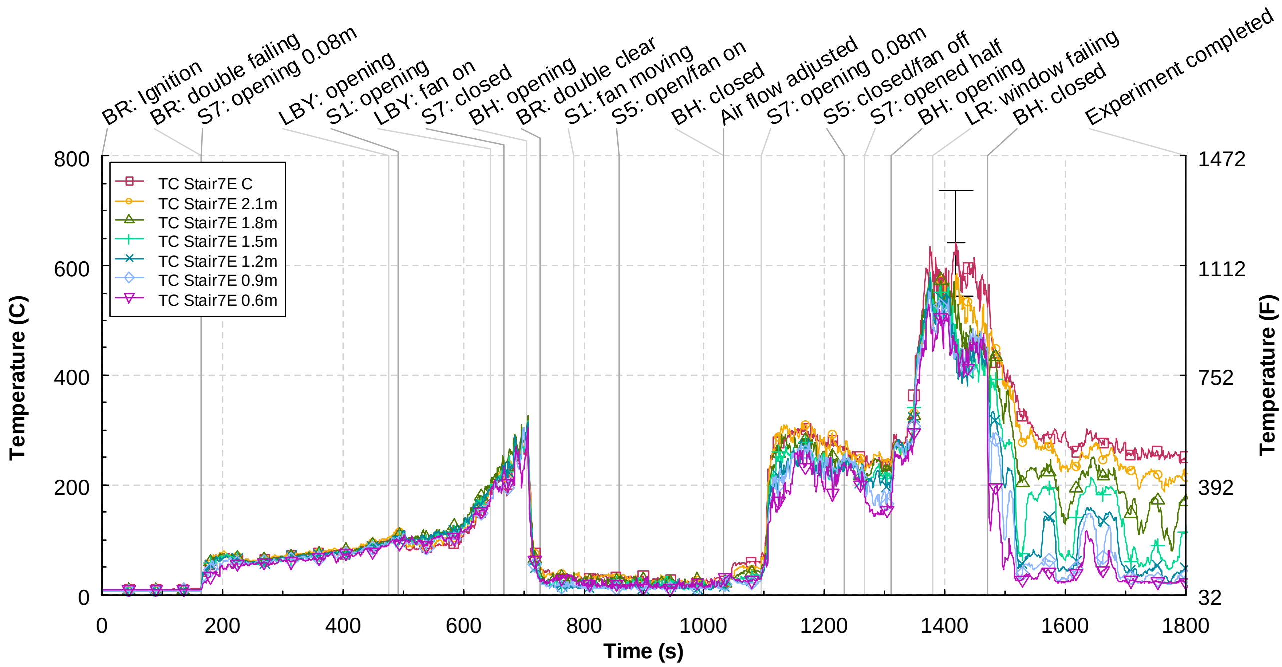



**Figure 9.4-27. Temperature versus time for the 7th floor stairwell thermocouple tree, Experiment 7E**

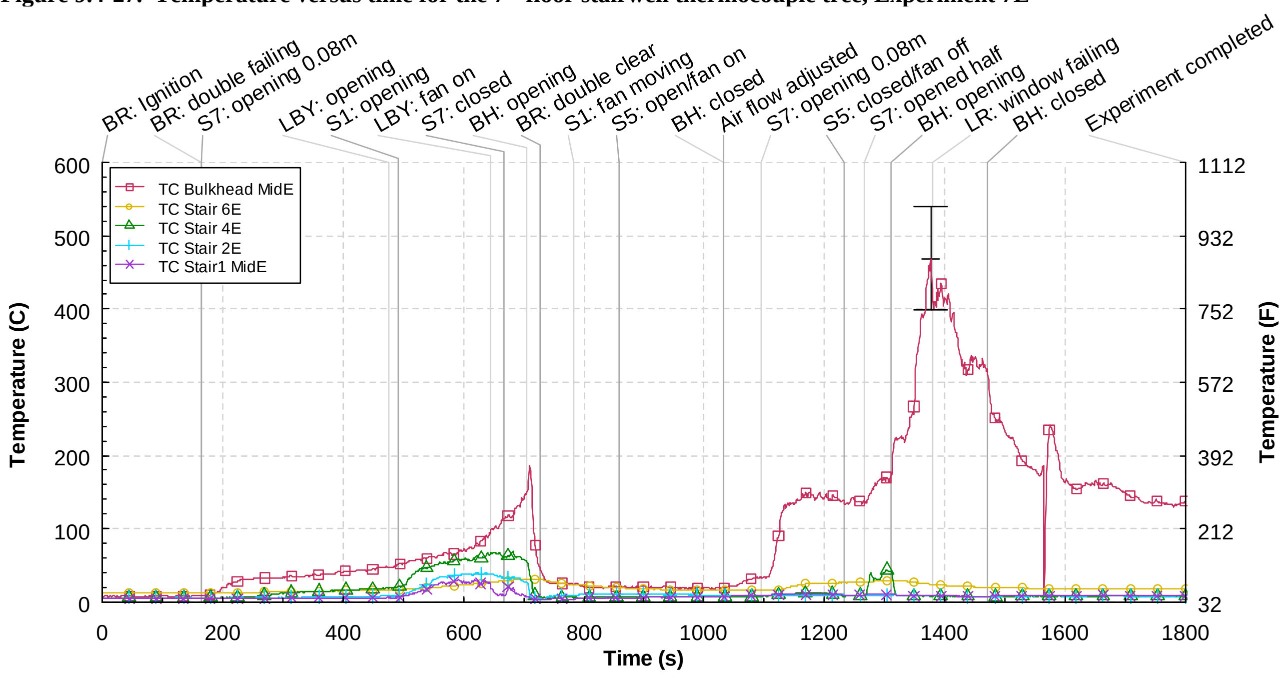



**Figure 9.4-28. Temperature versus time for the stair thermocouples, Experiment 7E**

### 9.4.3.2 Pressures

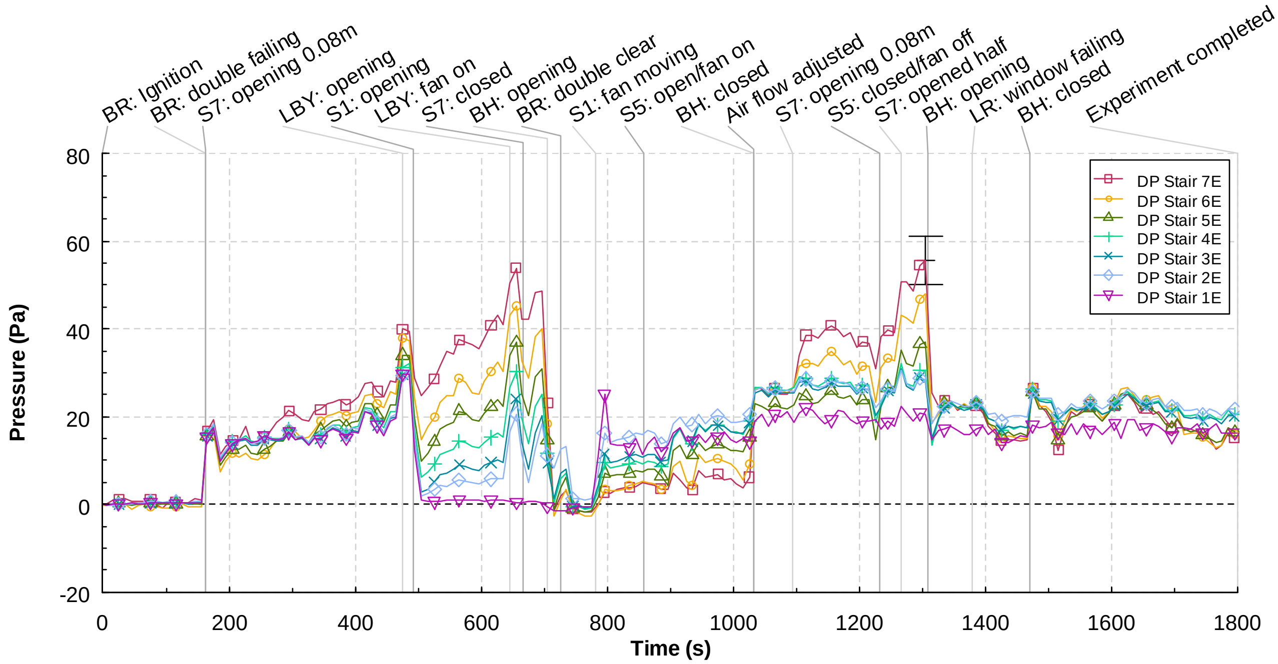



**Figure 9.4-29. Differential pressure versus time for the stairwell bi-directional probes, Experiment 7E**

### 9.4.3.3 Velocities

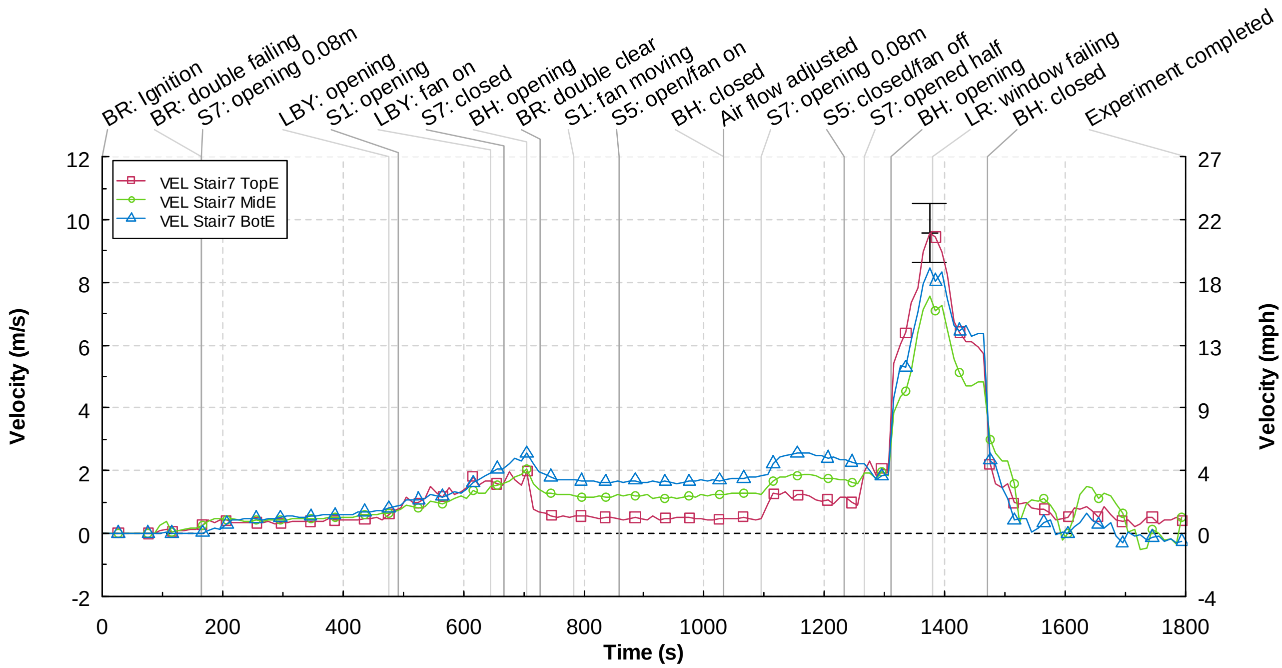



**Figure 9.4-30. Velocity versus time for the 7th floor stairwell bi-directional probes, Experiment 7E**

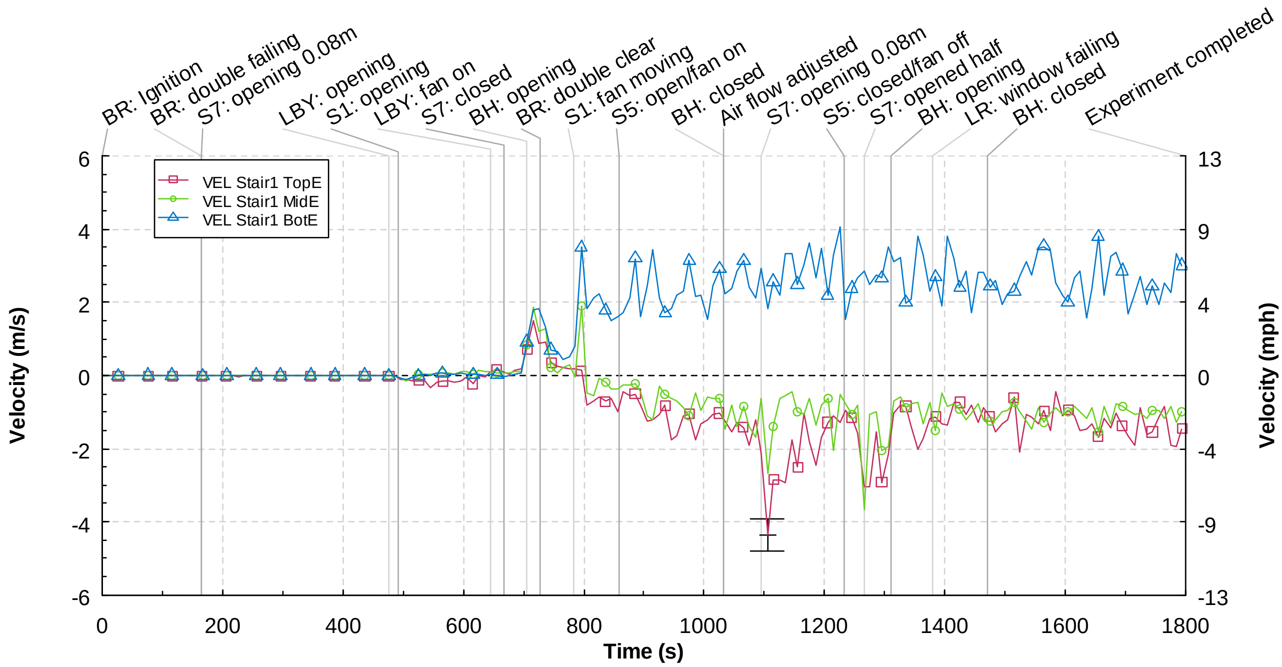



**Figure 9.4-31. Velocity versus time for the 1st floor stairwell bi-directional probes, Experiment 7E**

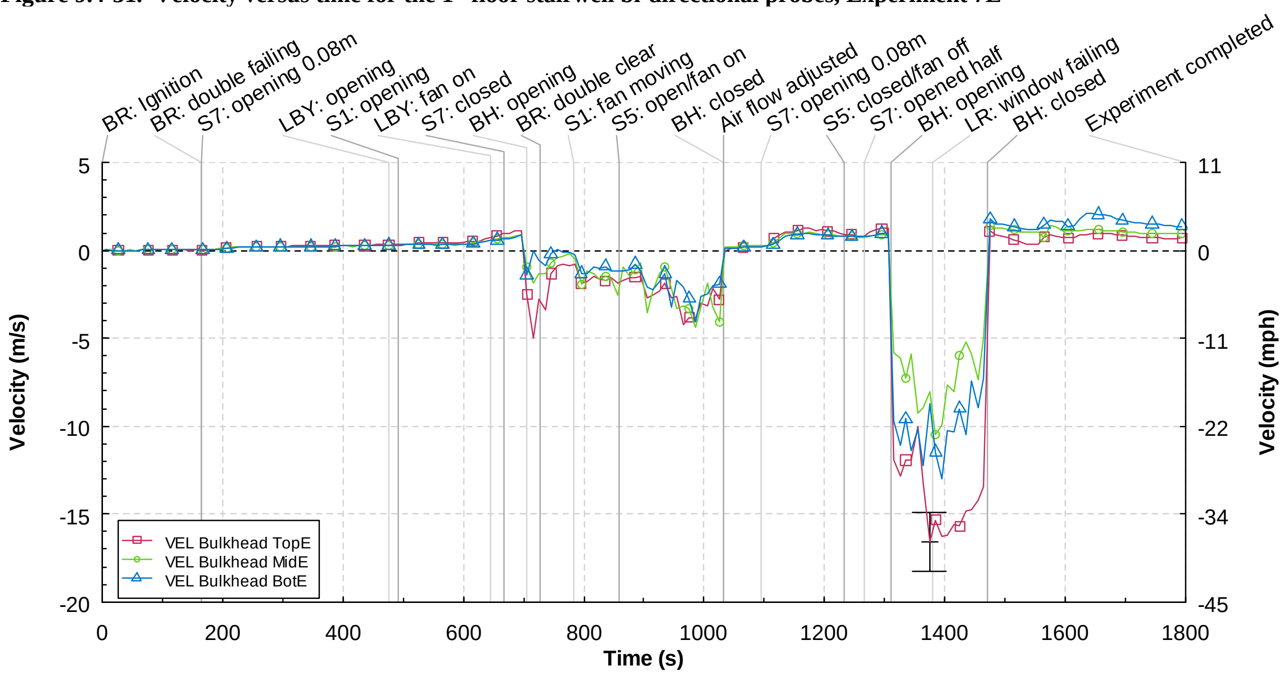



**Figure 9.4-32. Velocity versus time for the bulkhead bi-directional probes, Experiment 7E**

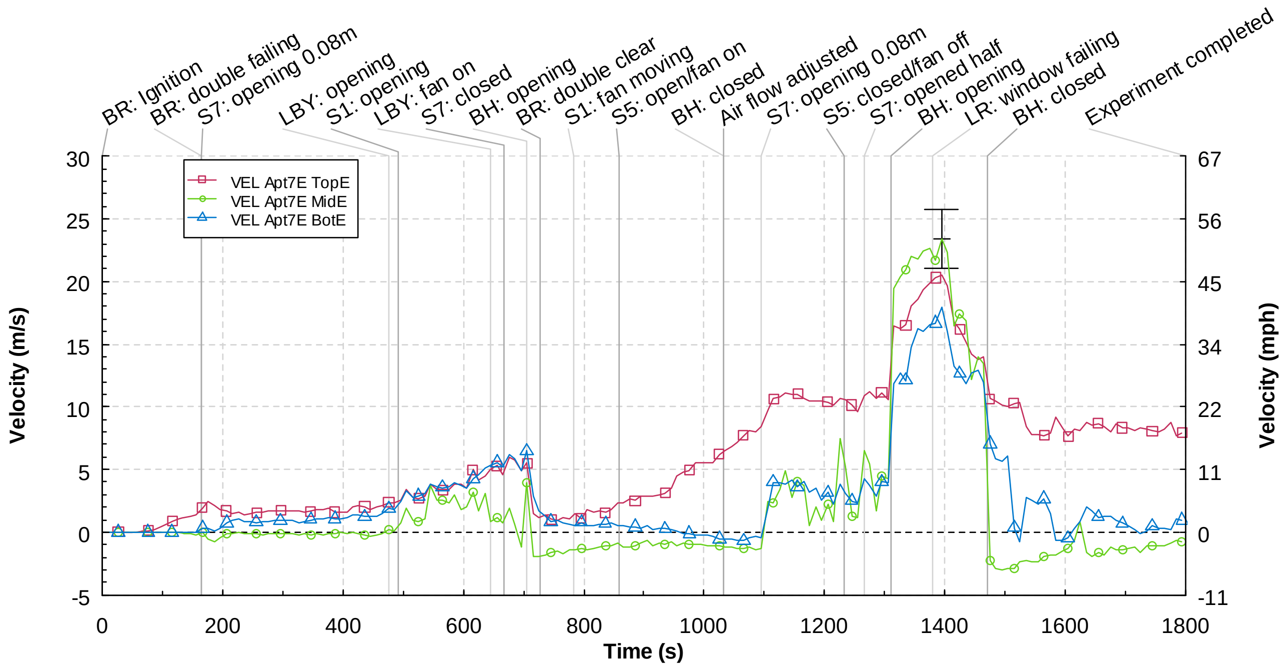



**Figure 9.4-33. Velocity versus time for the apartment 7E doorway bi-directional probes, Experiment 7E**

## 9.4.4 Experiment 7A

### 9.4.4.1 Temperatures

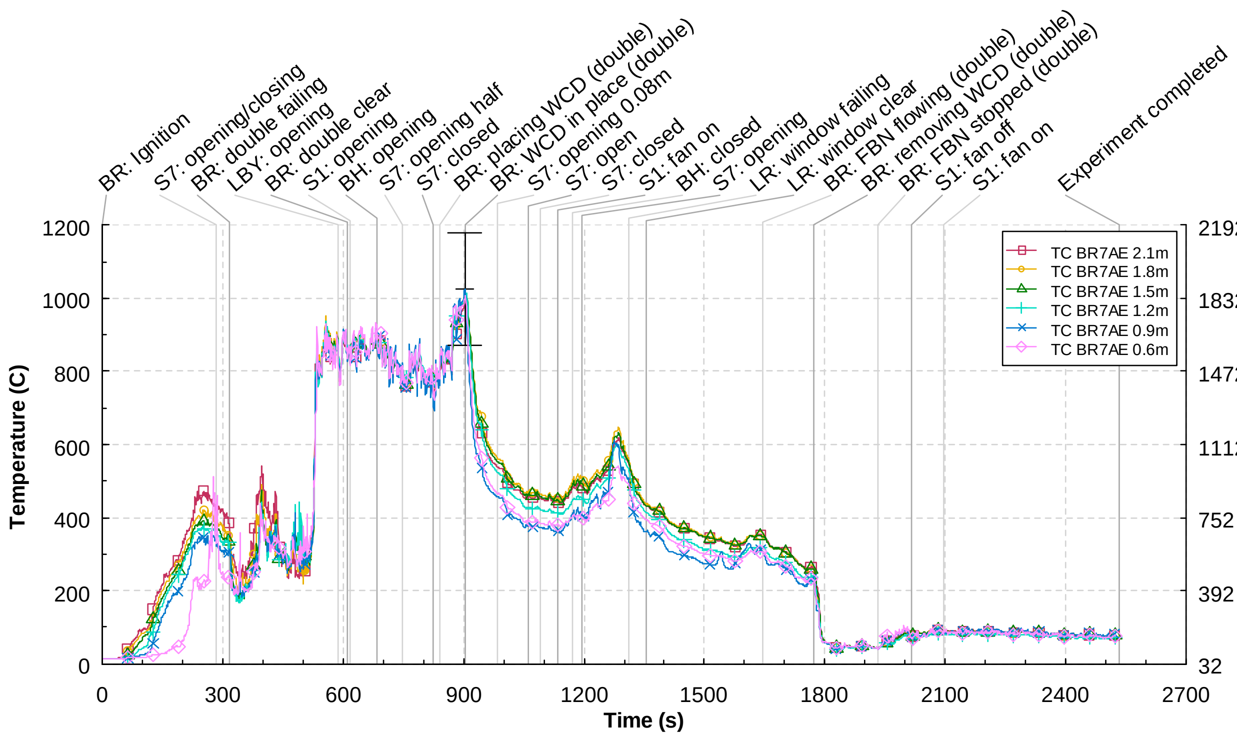



**Figure 9.4-34. Temperature versus time for the 7A bedroom thermocouple tree, Experiment 7A**

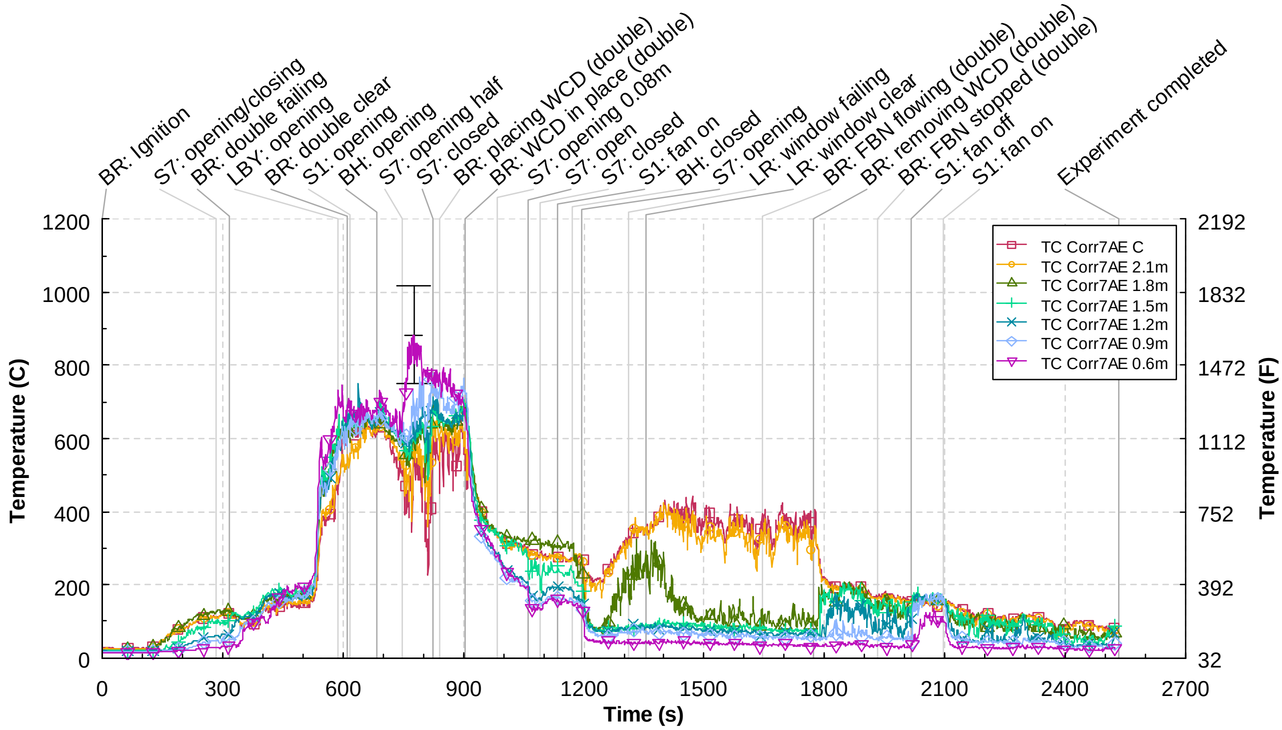



**Figure 9.4-35. Temperature versus time for the 7A hall thermocouple tree, Experiment 7A**

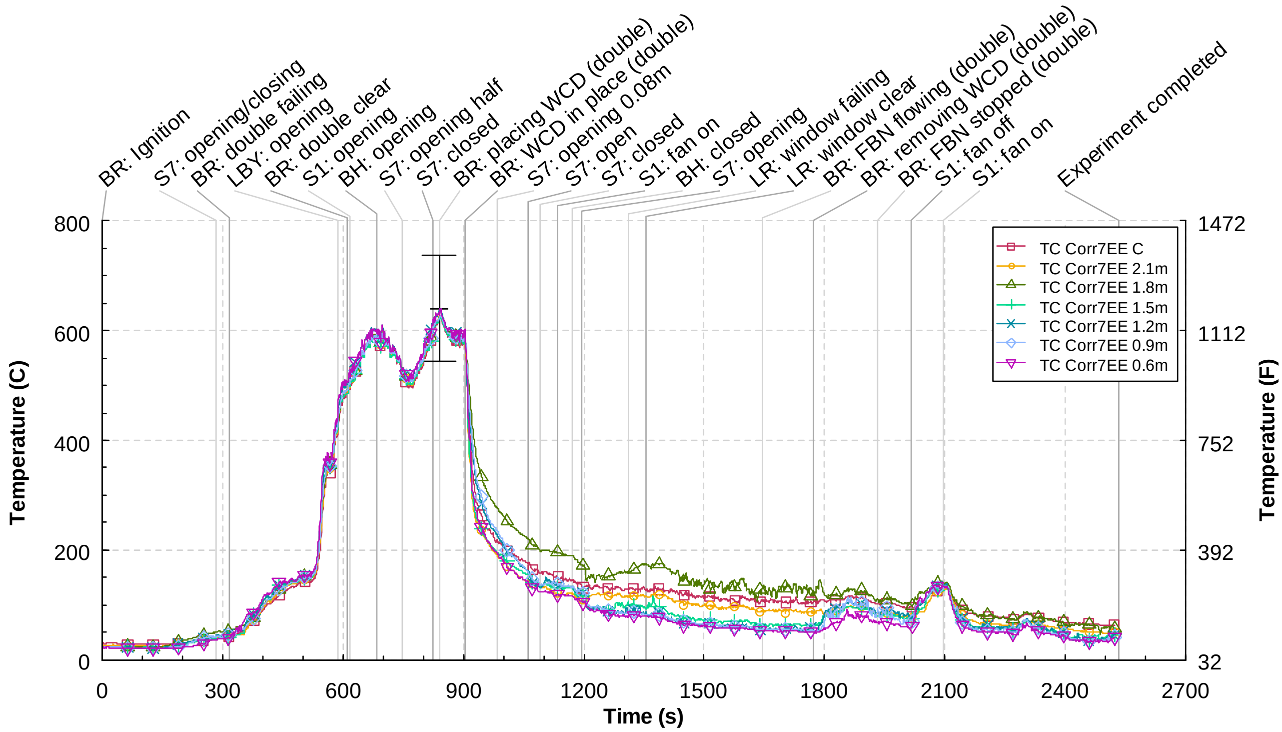



**Figure 9.4-36. Temperature versus time for the 7E hall thermocouple tree, Experiment 7A**

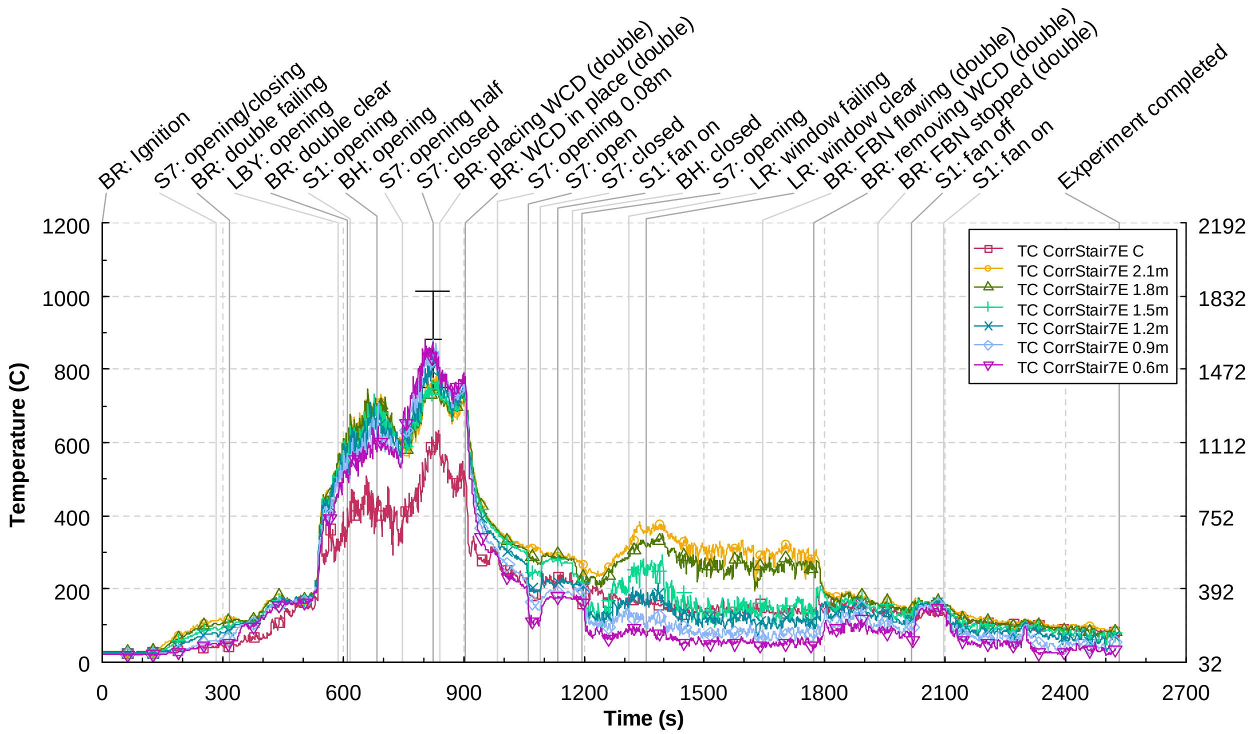



**Figure 9.4-37. Temperature versus time for the 7th floor stair hall thermocouple tree, Experiment 7A**

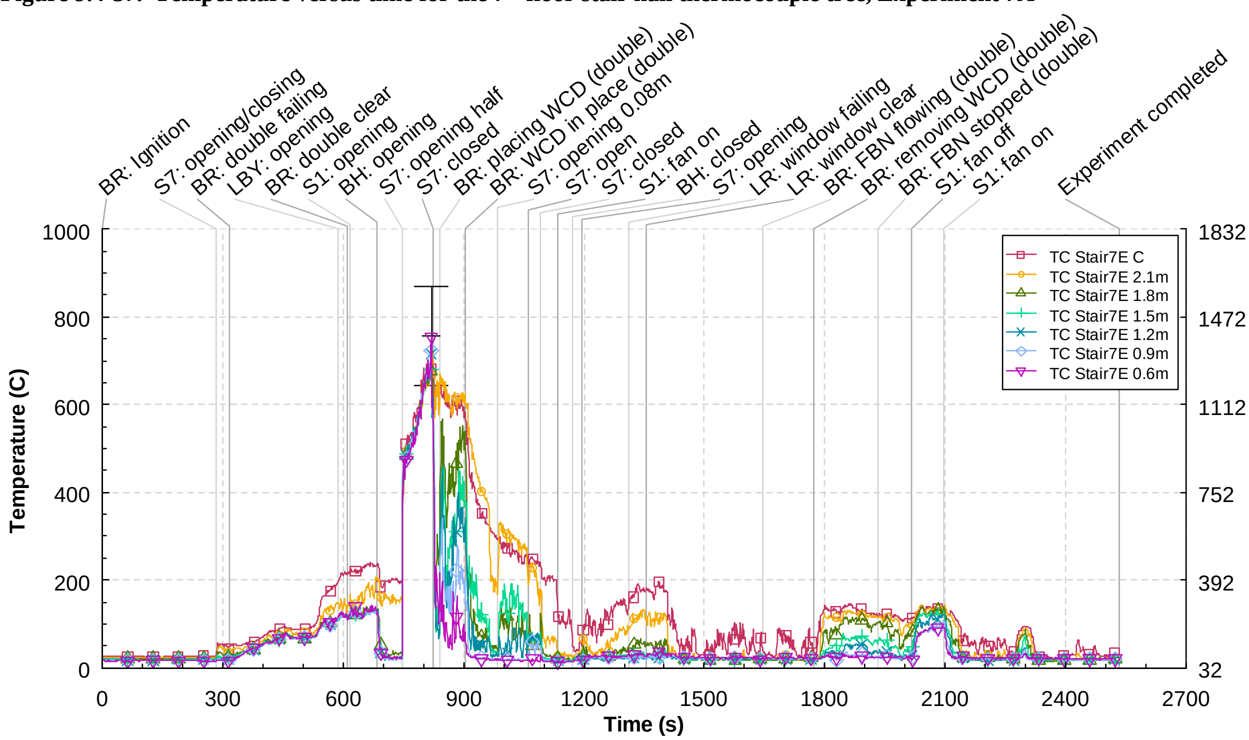



**Figure 9.4-38. Temperature versus time for the 7th floor stairwell thermocouple tree, Experiment 7A**

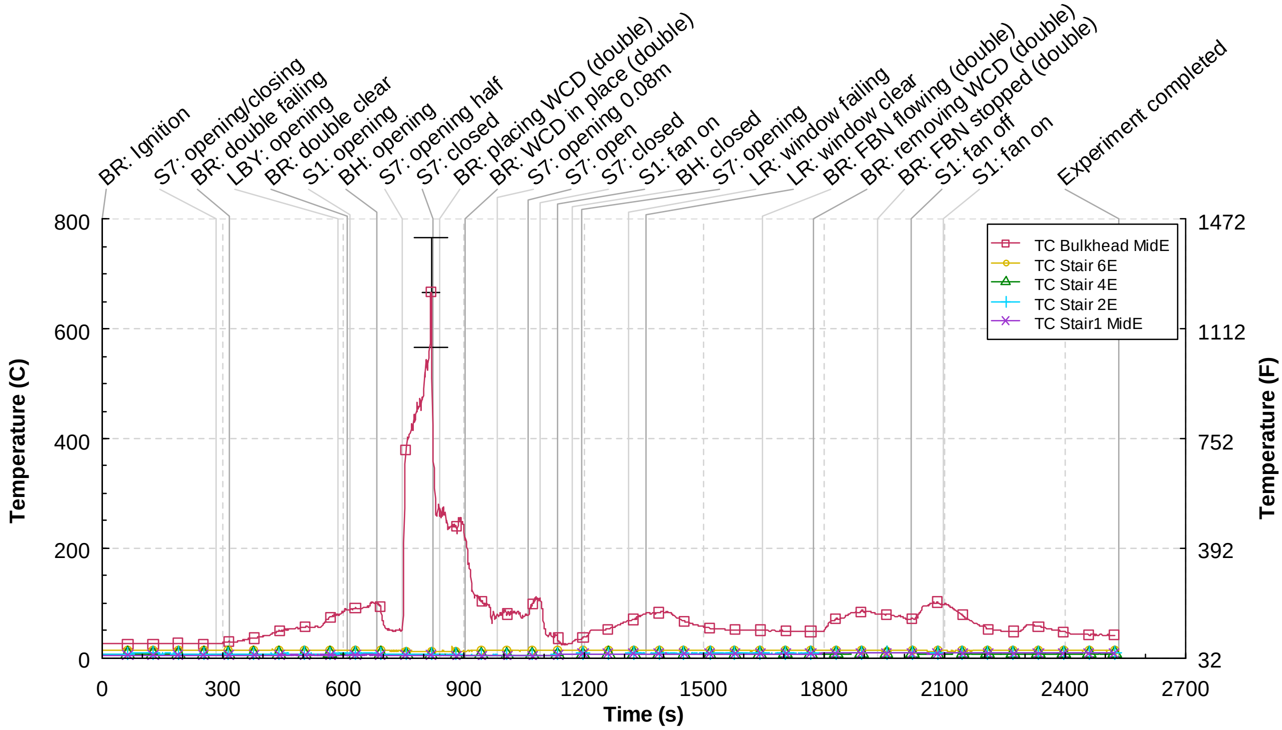



**Figure 9.4-39. Temperature versus time for the stair thermocouples, Experiment 7A**

### 9.4.4.2 Pressures

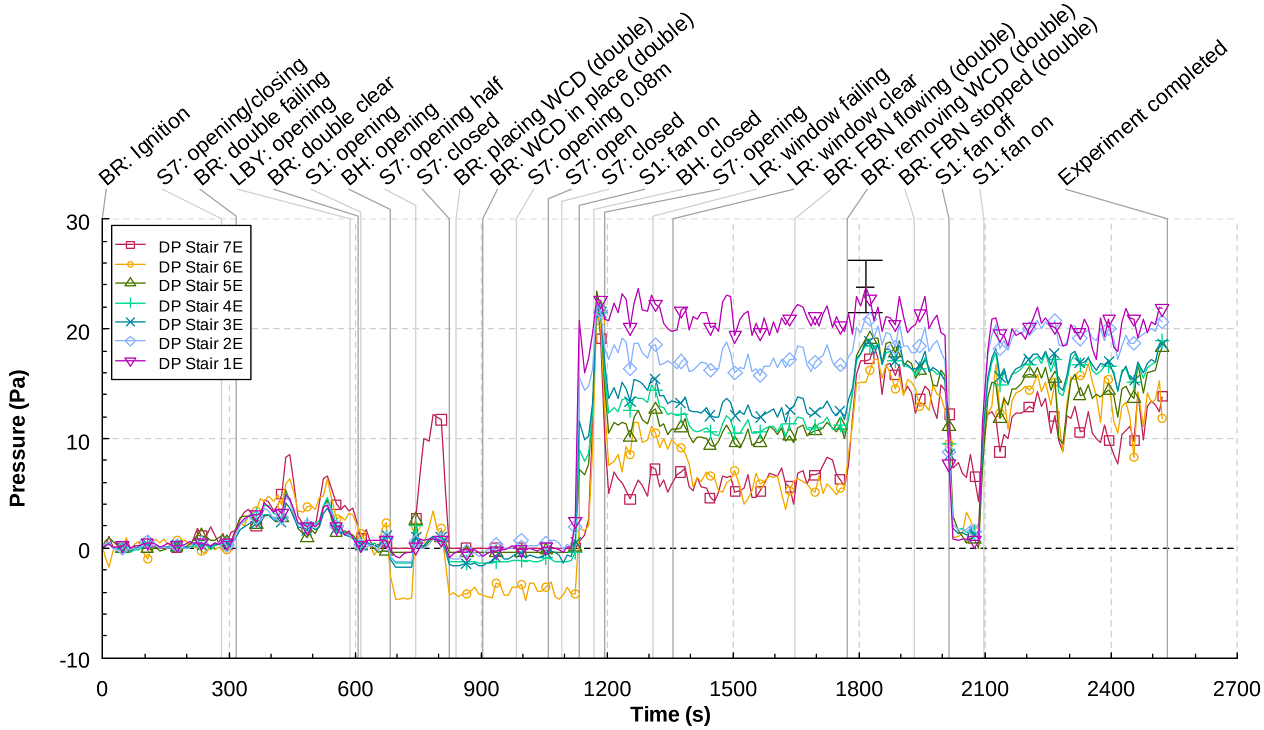



**Figure 9.4-40. Differential pressure versus time for the stairwell bi-directional probes, Experiment 7A**

### 9.4.4.3 Velocities

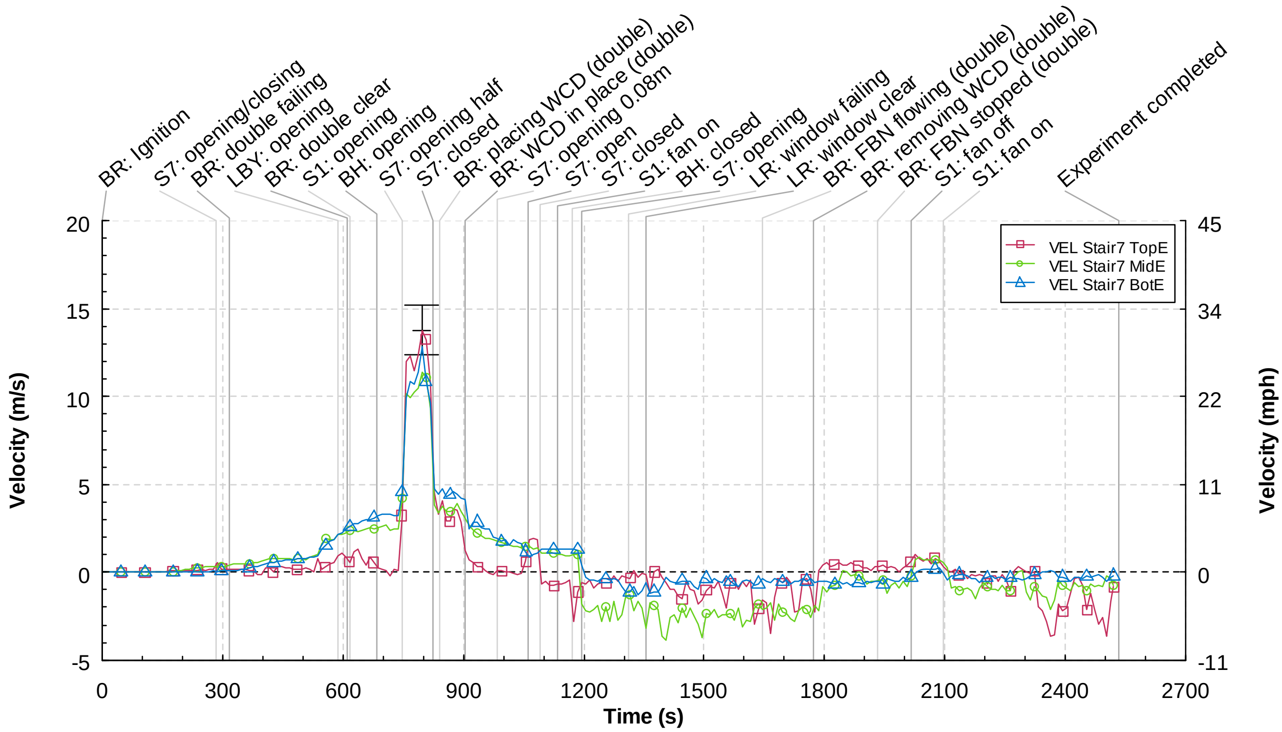



**Figure 9.4-41. Velocity versus time for the 7th floor stairwell bi-directional probes, Experiment 7A**

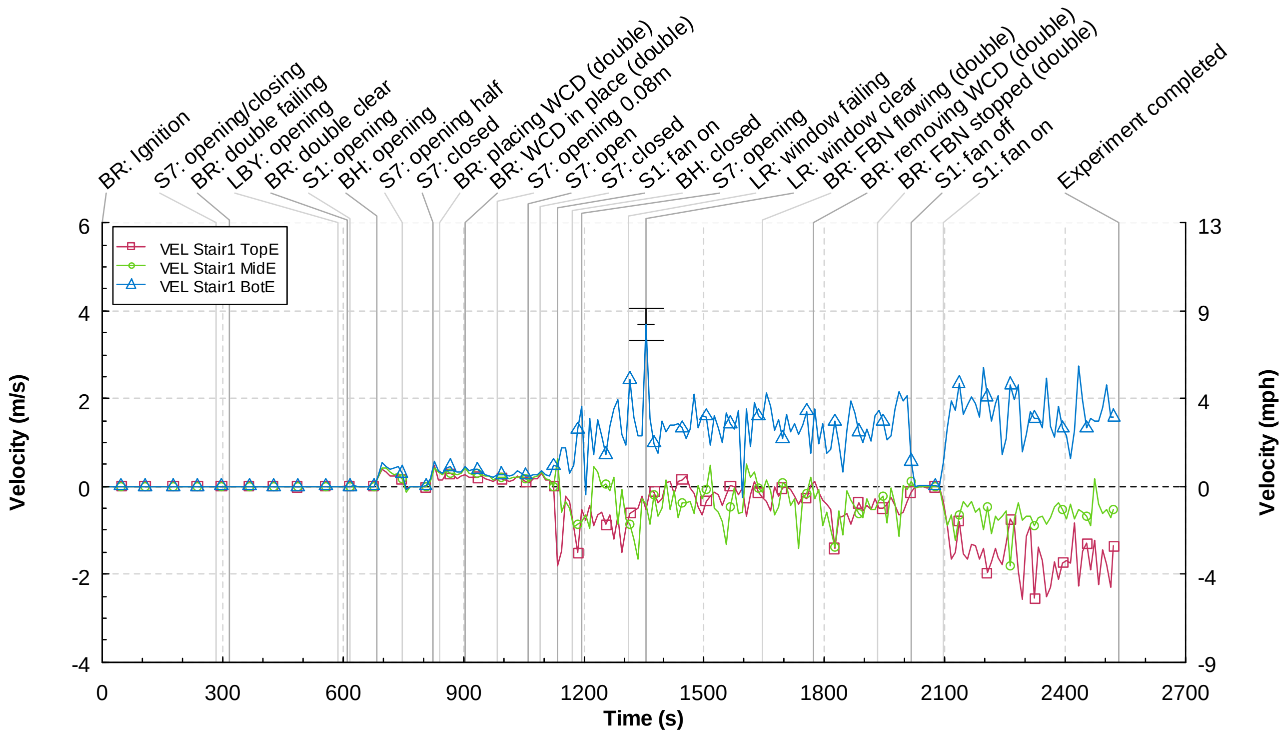



**Figure 9.4-42. Velocity versus time for the 1st floor stairwell bi-directional probes, Experiment 7A**

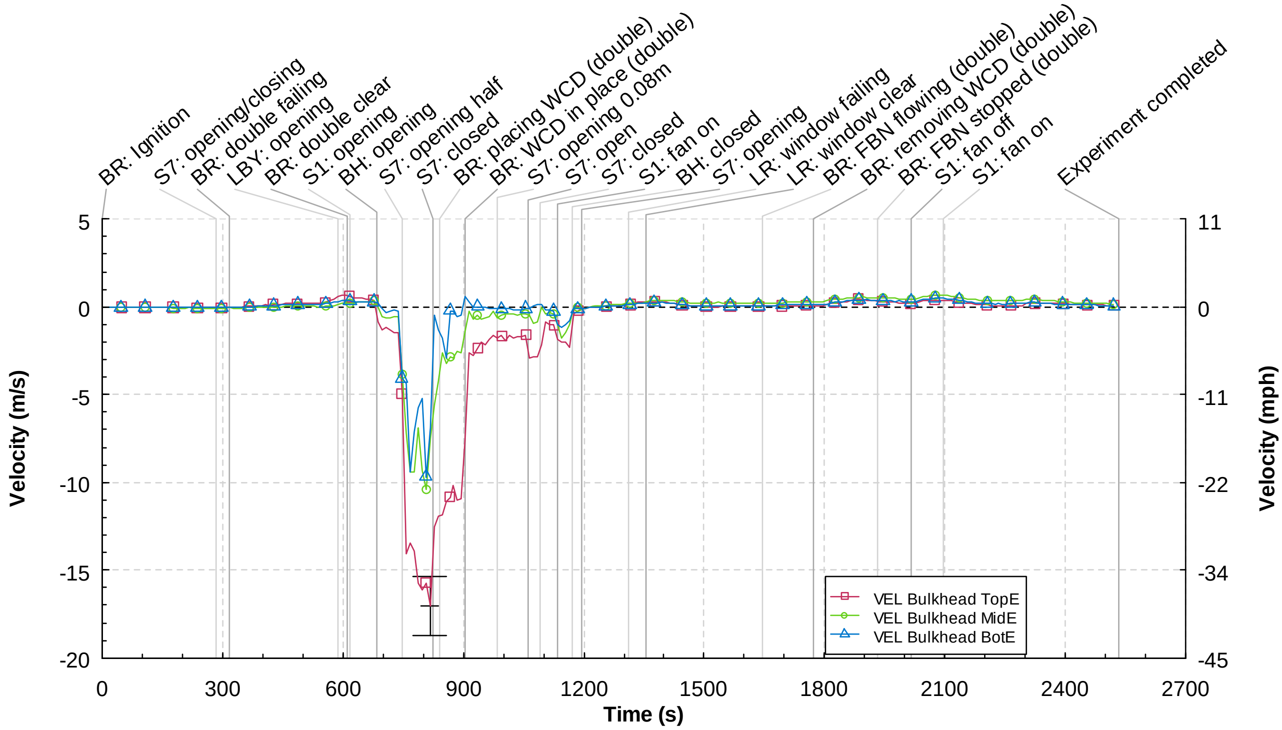



**Figure 9.4-43. Velocity versus time for the bulkhead bi-directional probes, Experiment 7A**

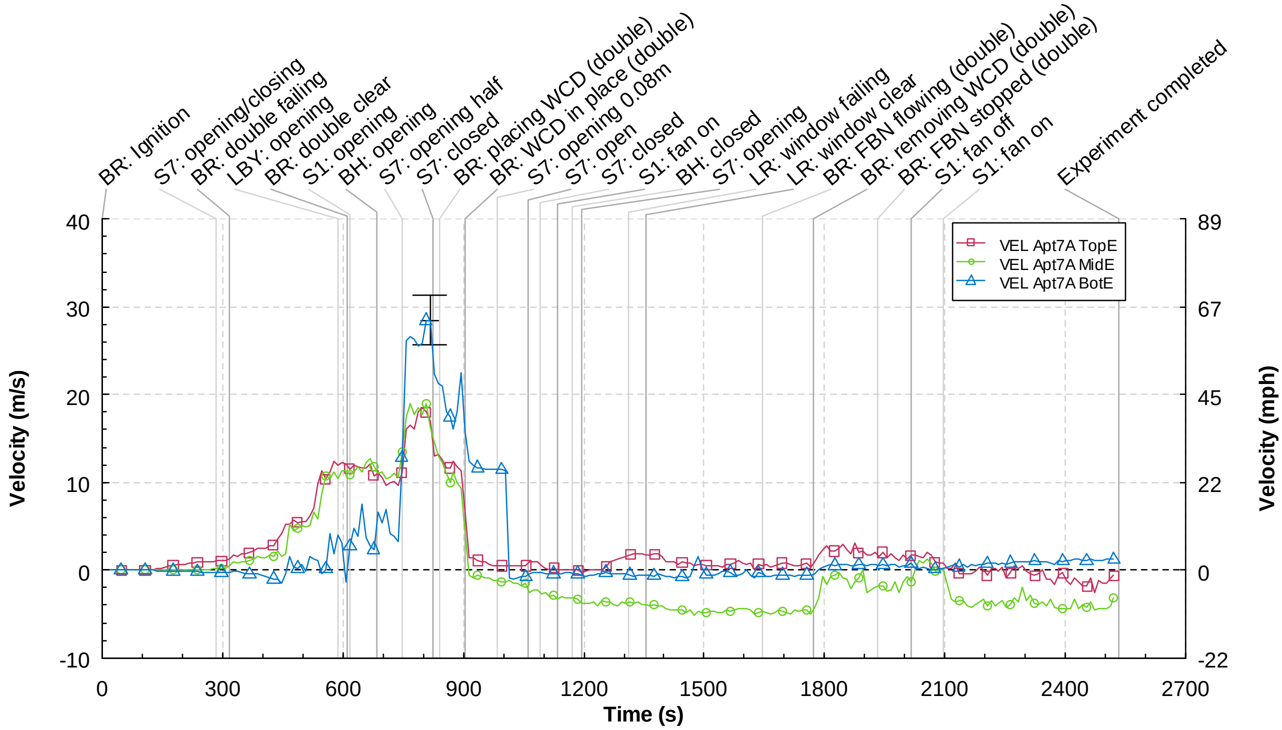



**Figure 9.4-44. Velocity versus time for the apartment 7A doorway bi-directional probes, Experiment 7A**

## 9.4.5 Experiment 7K

### 9.4.5.1 Temperatures

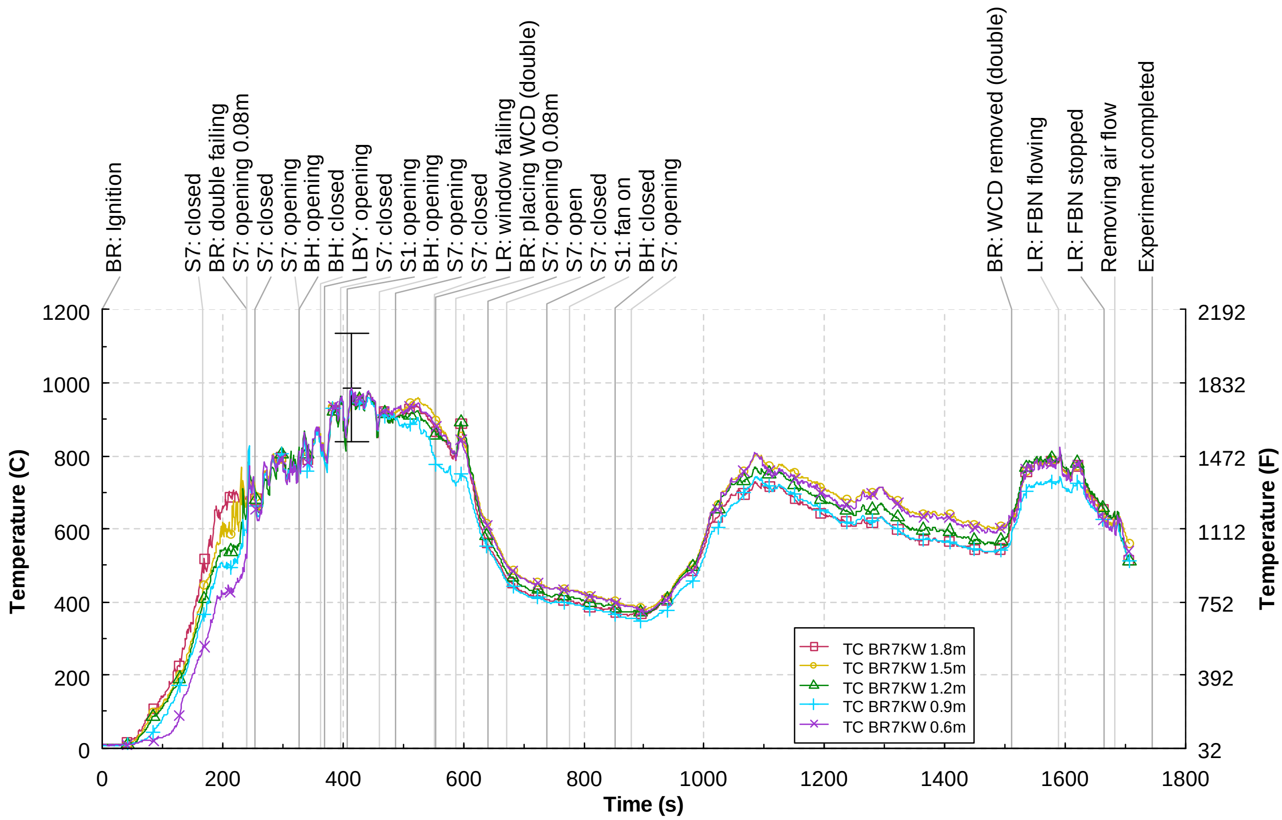



**Figure 9.4-45. Temperature versus time for the 7K bedroom thermocouple tree, Experiment 7K**

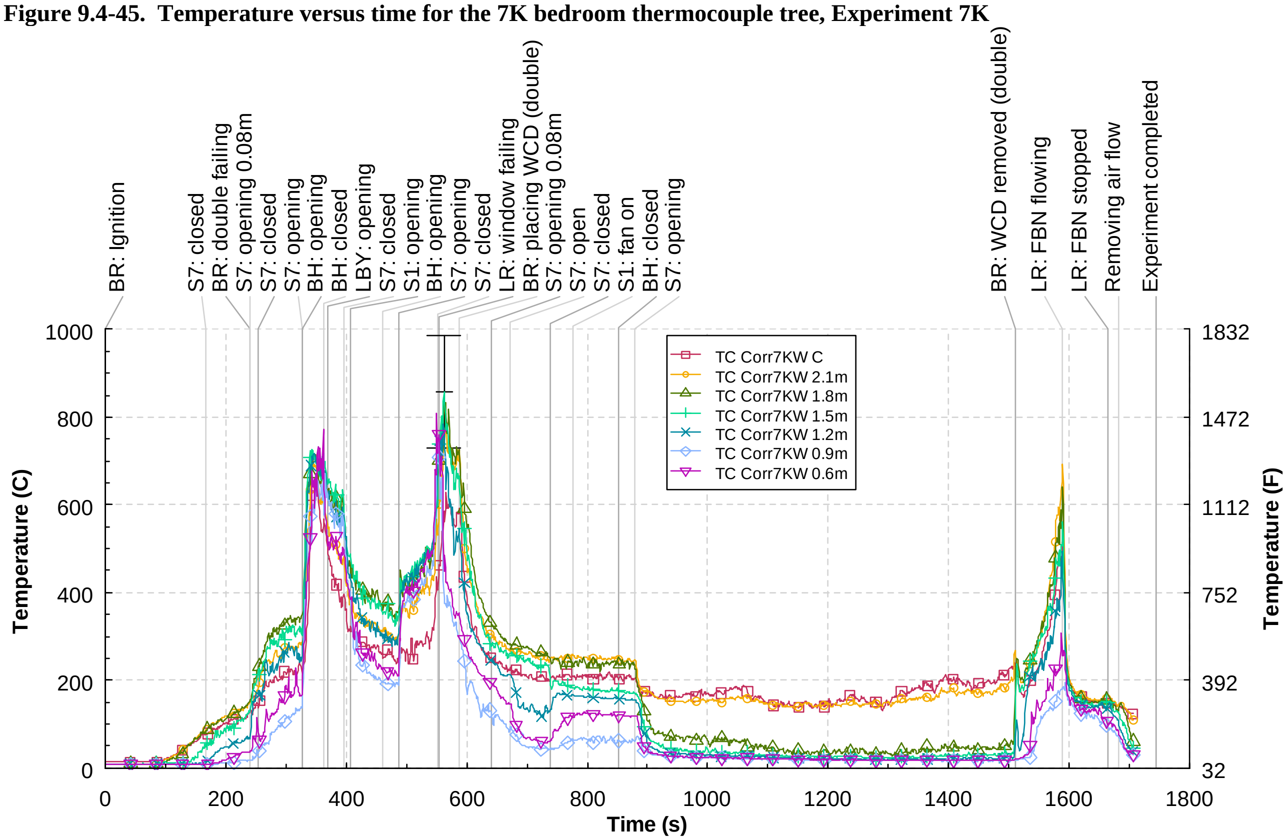



**Figure 9.4-46. Temperature versus time for the 7K hall thermocouple tree, Experiment 7K**

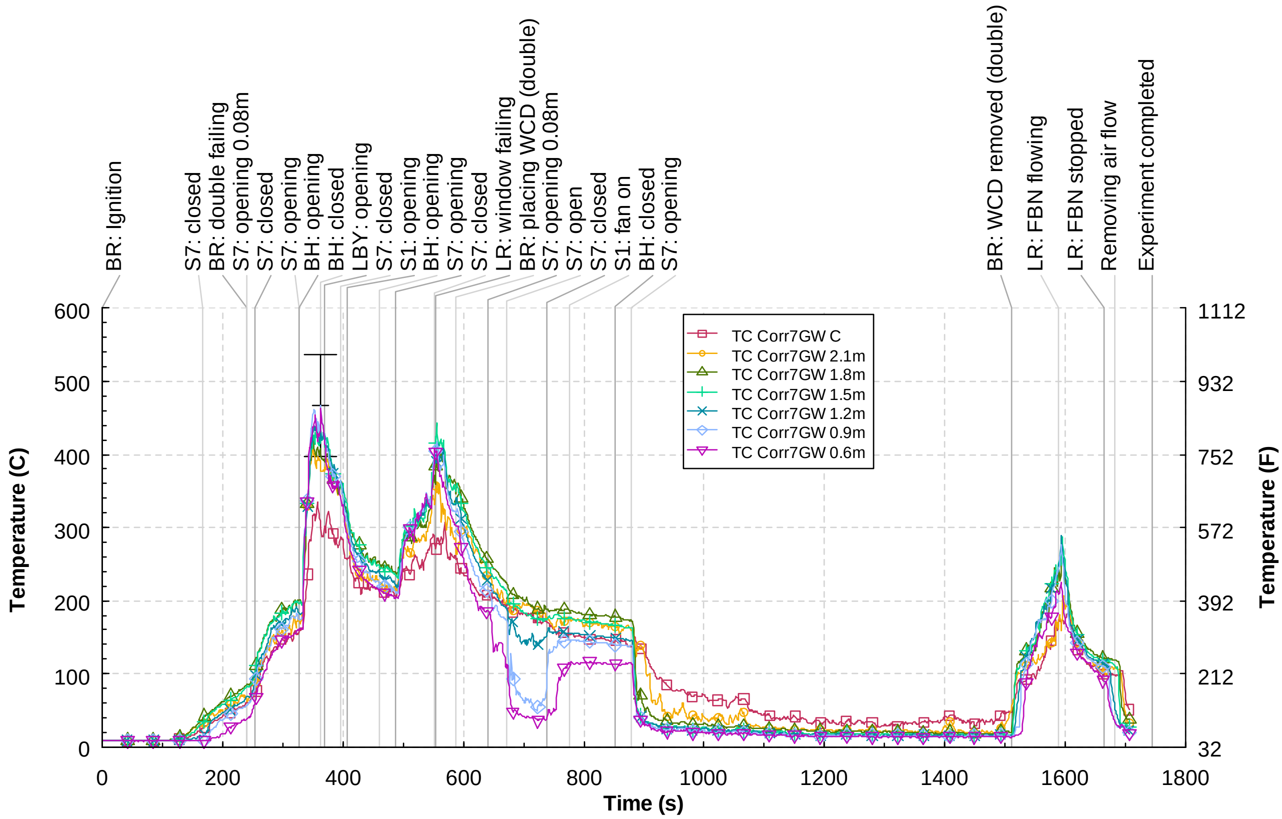



**Figure 9.4-47. Temperature versus time for the 7G hall thermocouple tree, Experiment 7K**

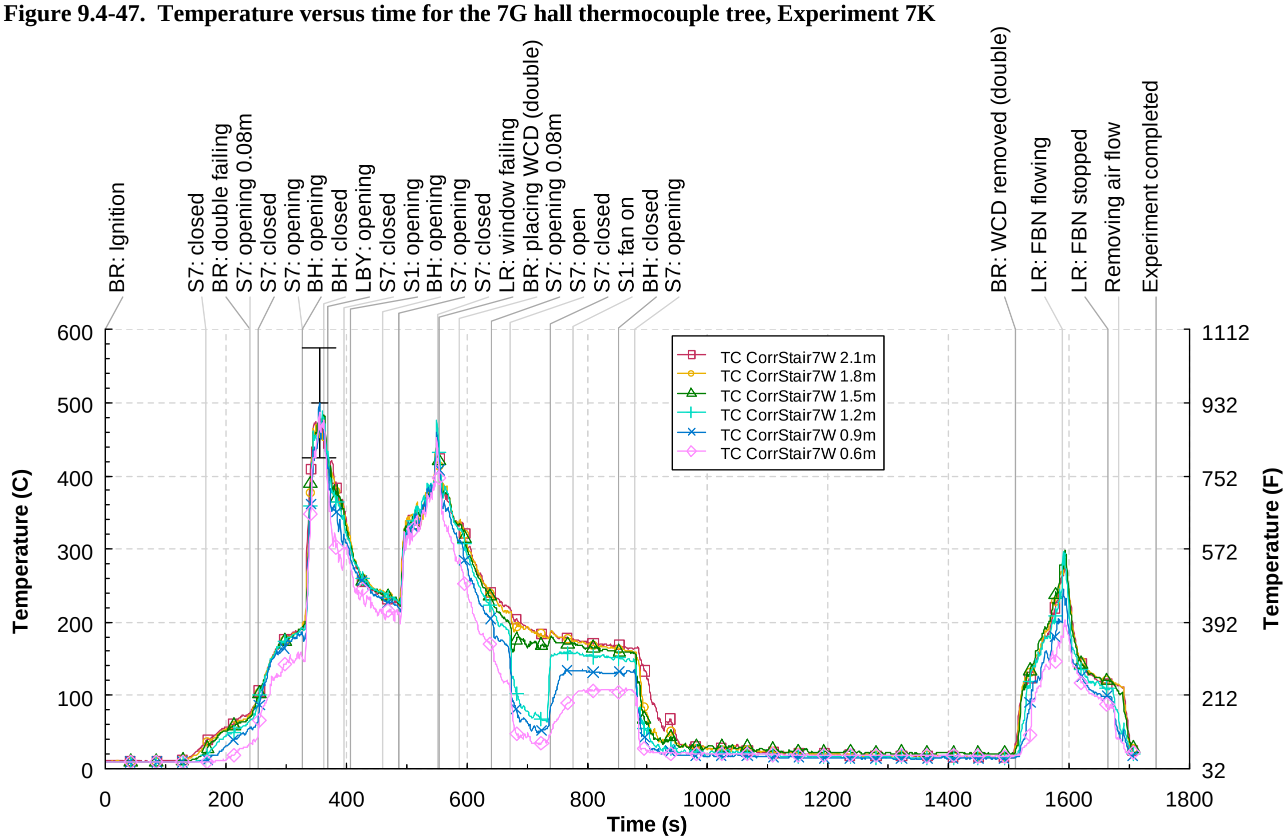



**Figure 9.4-48. Temperature versus time for the 7th floor stair hall thermocouple tree, Experiment 7K**

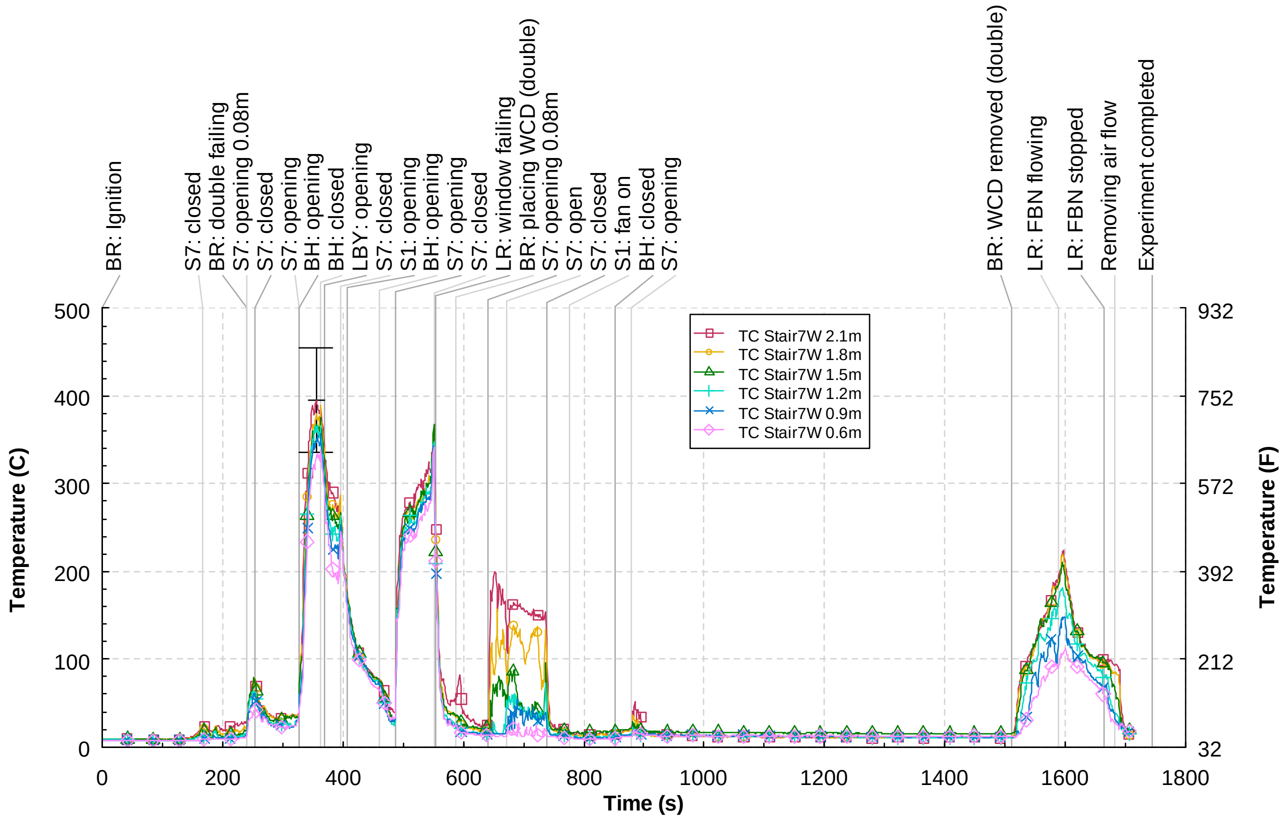



**Figure 9.4-49. Temperature versus time for the 7th floor stairwell thermocouple tree, Experiment 7K**

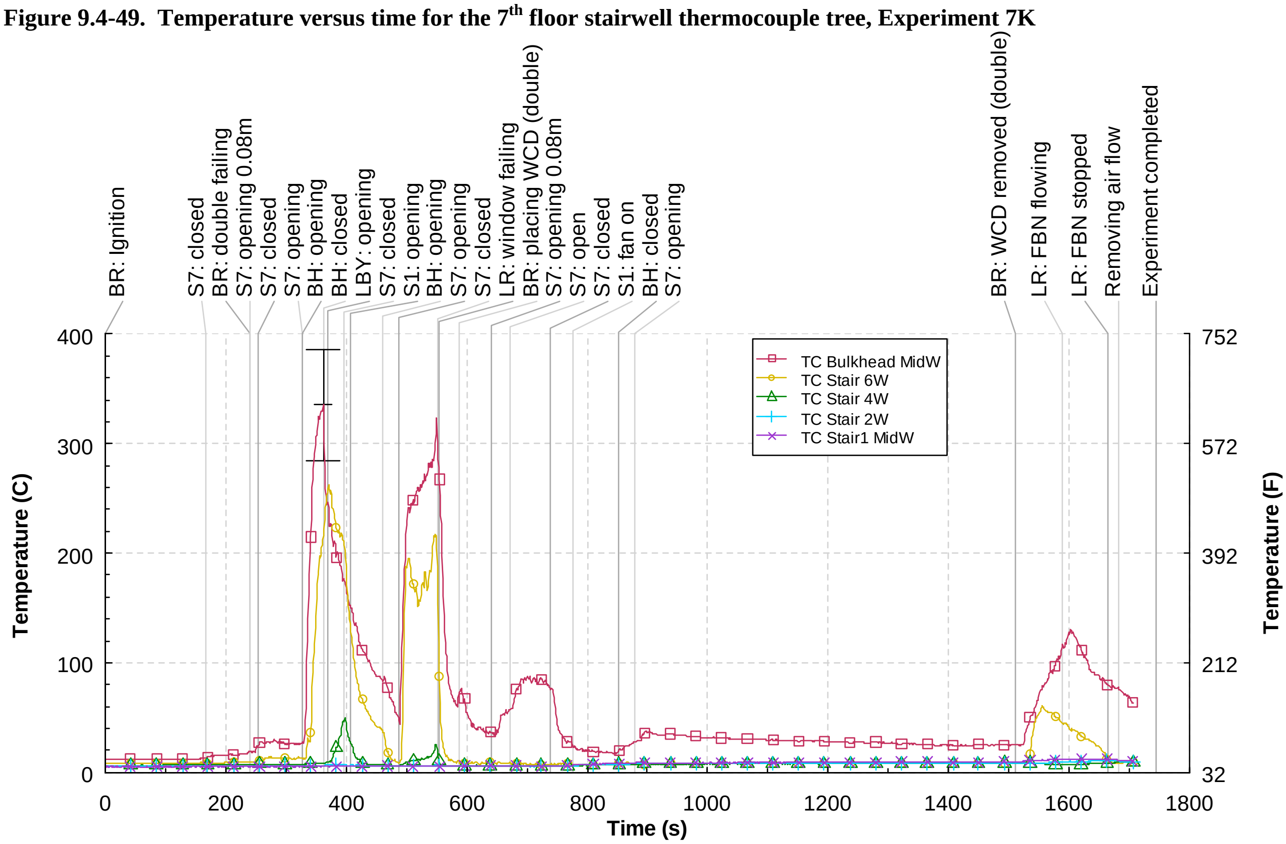



**Figure 9.4-50. Temperature versus time for the stair thermocouples, Experiment 7K**

### 9.4.5.2 Pressures

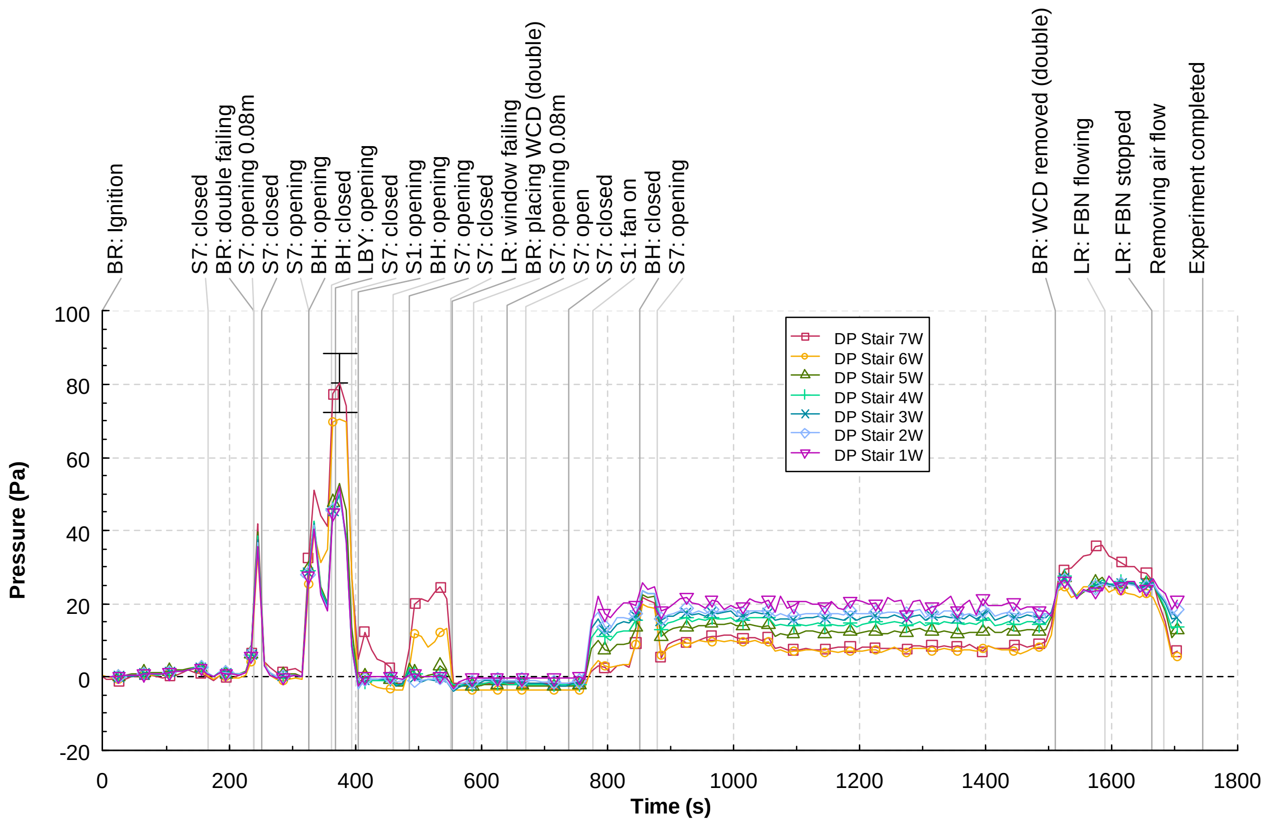



**Figure 9.4-51. Differential pressure versus time for the stairwell bi-directional probes, Experiment 7K**

### 9.4.5.3 Velocities

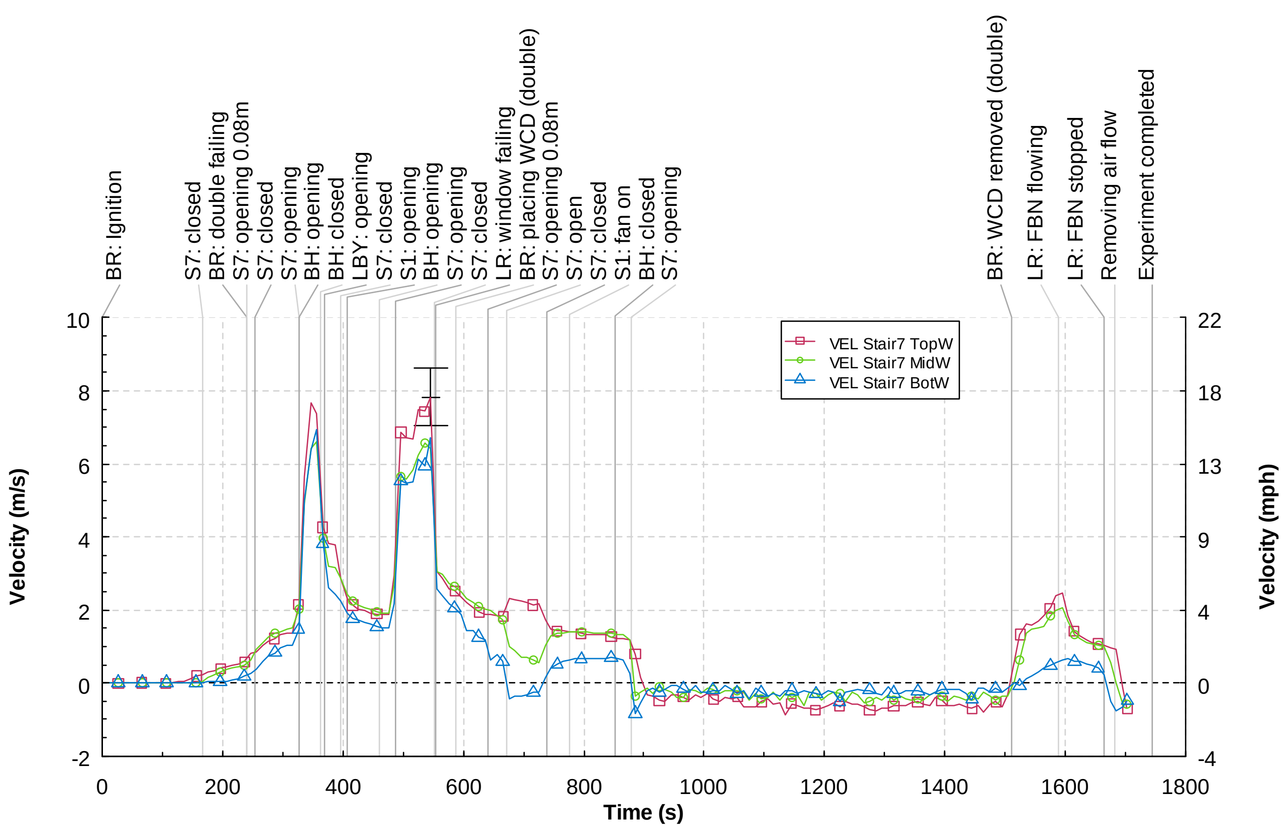



**Figure 9.4-52. Velocity versus time for the 7th floor stairwell bi-directional probes, Experiment 7K**

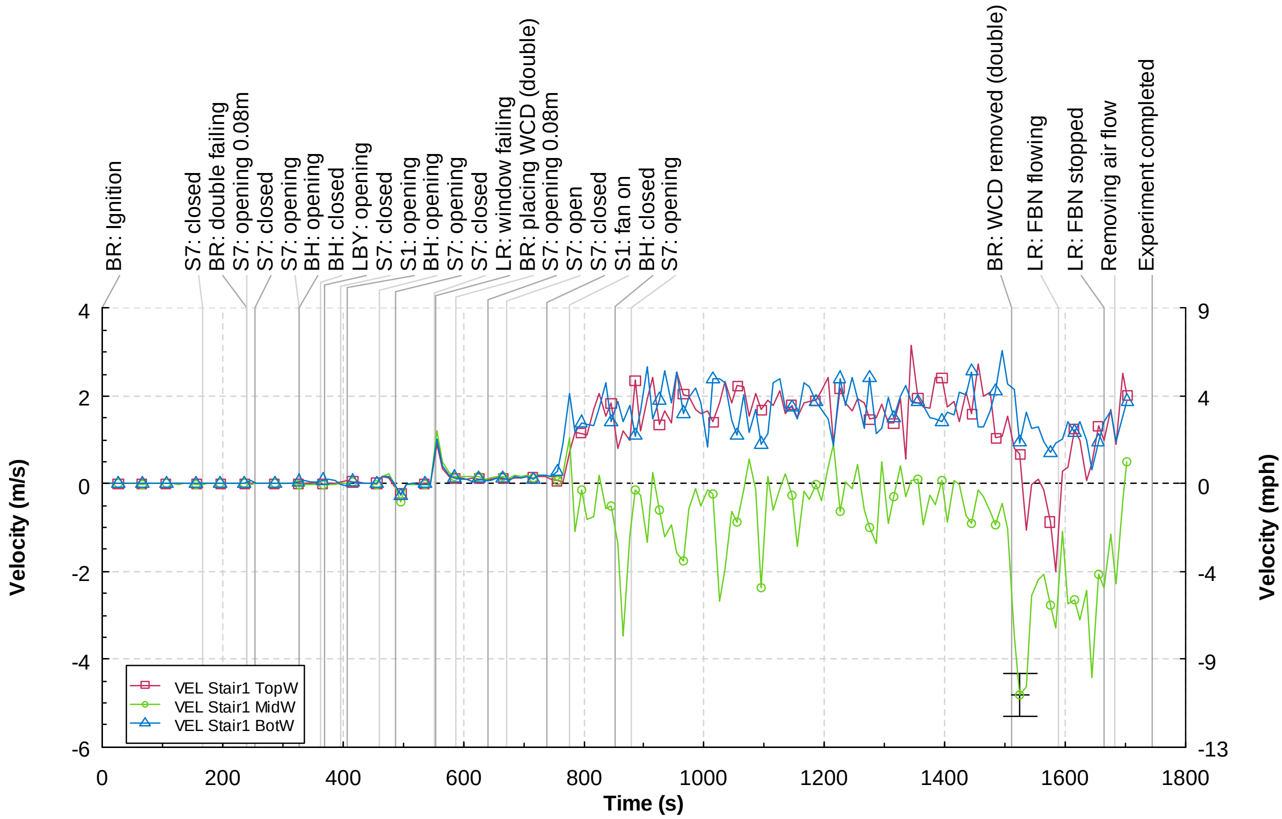



**Figure 9.4-53. Velocity versus time for the 1st floor stairwell bi-directional probes, Experiment 7K**

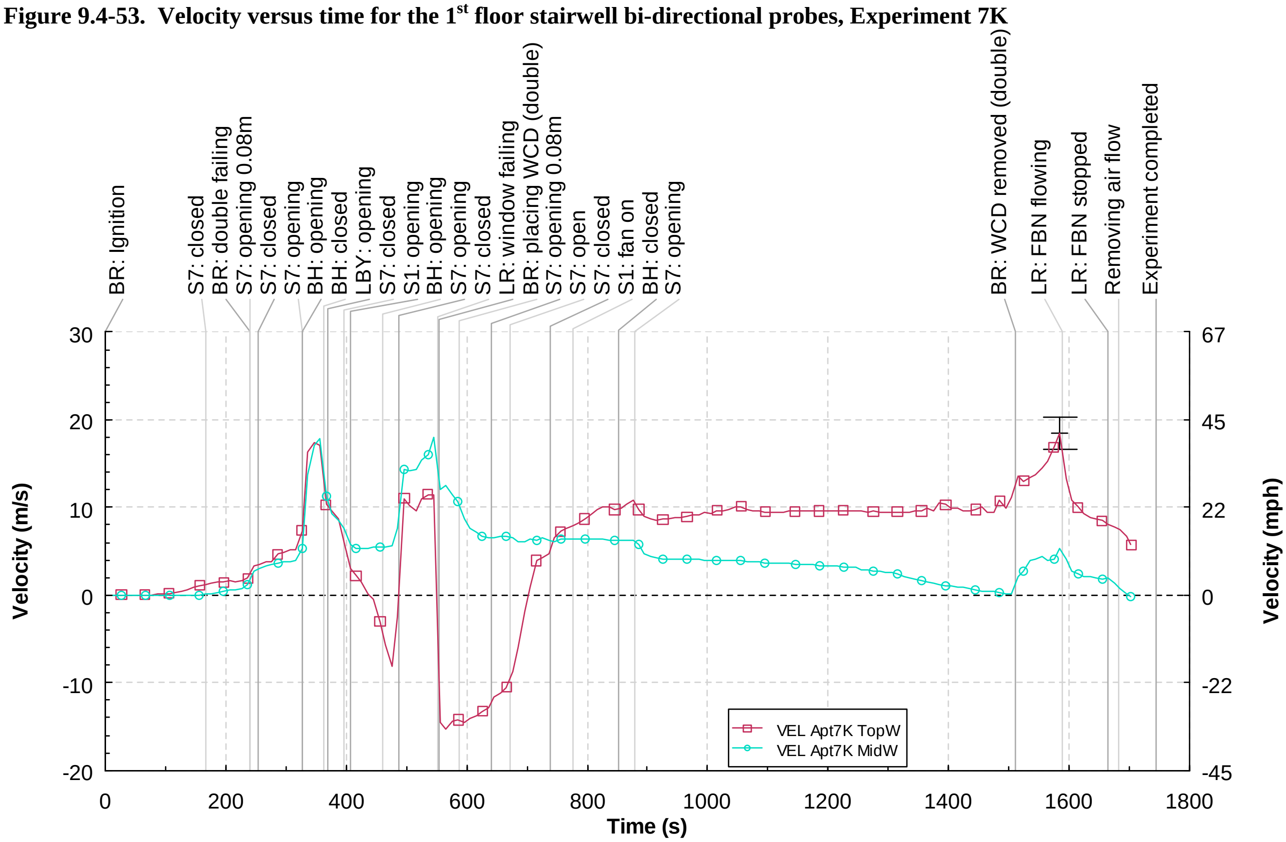



**Figure 9.4-54. Velocity versus time for the apartment 7K doorway bi-directional probes, Experiment 7K**

## 9.4.6 Experiment 5E

### 9.4.6.1 Temperatures

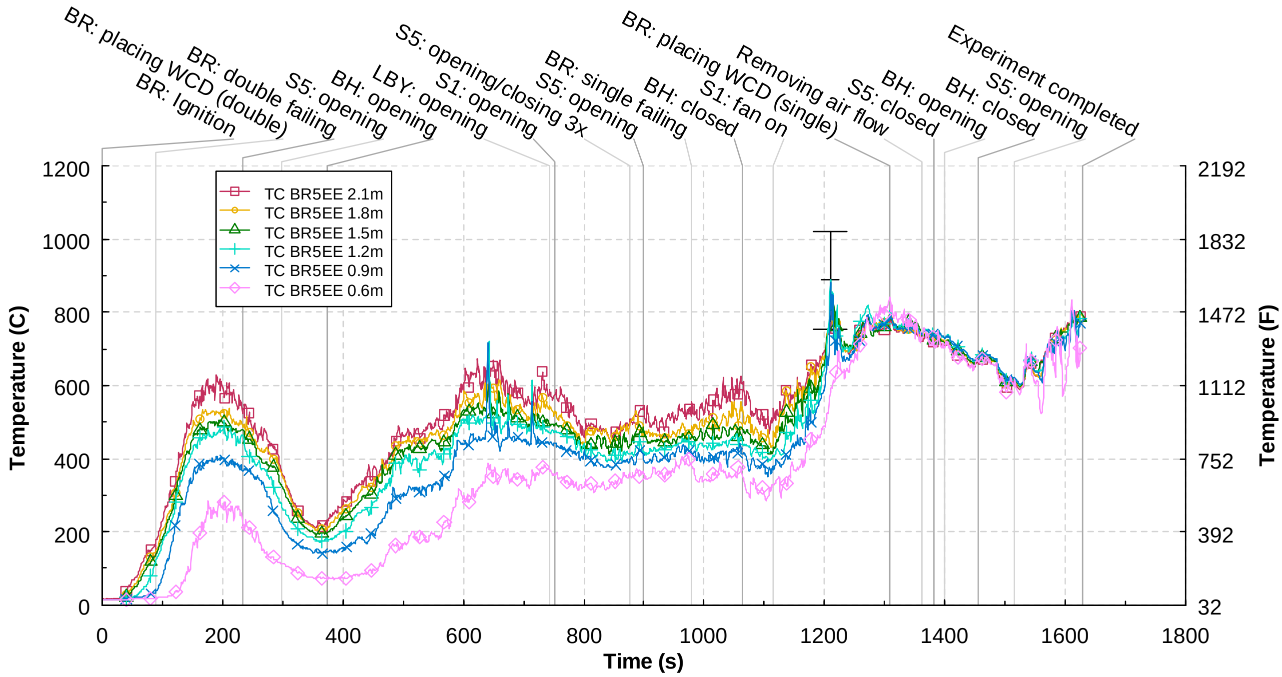



**Figure 9.4-55. Temperature versus time for the 5E bedroom thermocouple tree, Experiment 5E**

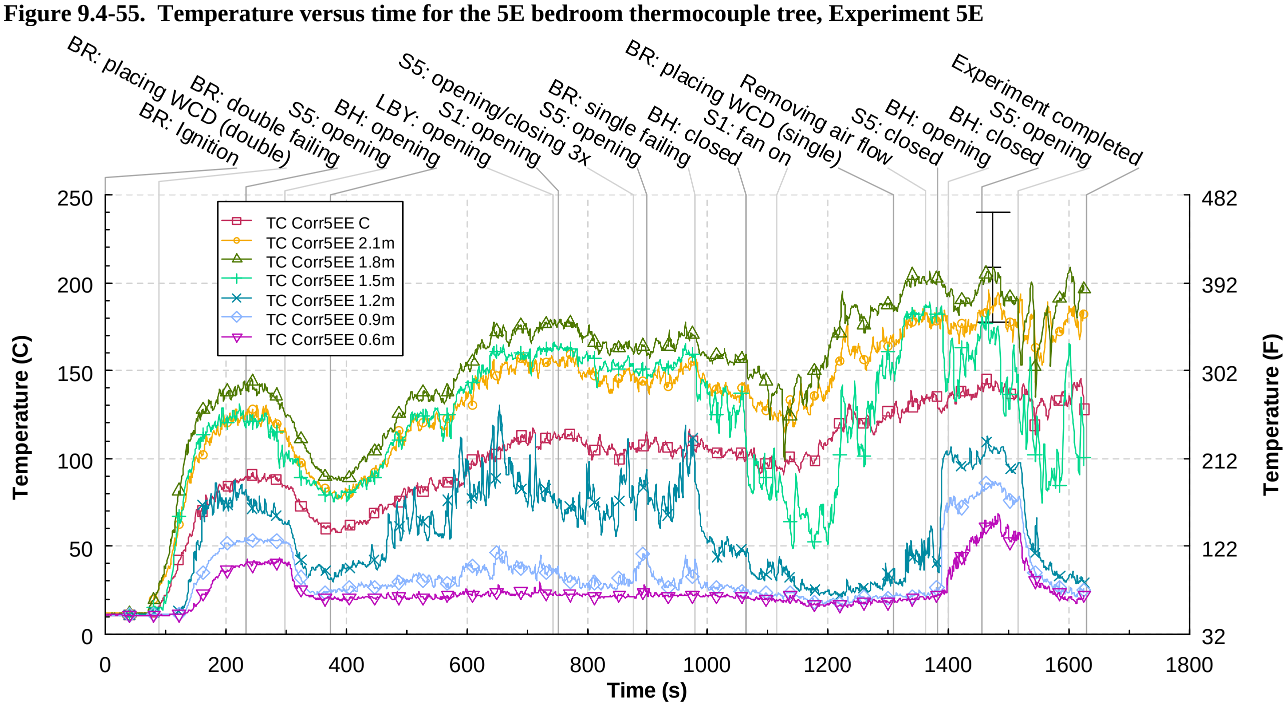



**Figure 9.4-56. Temperature versus time for the 5E hall thermocouple tree, Experiment 5E**

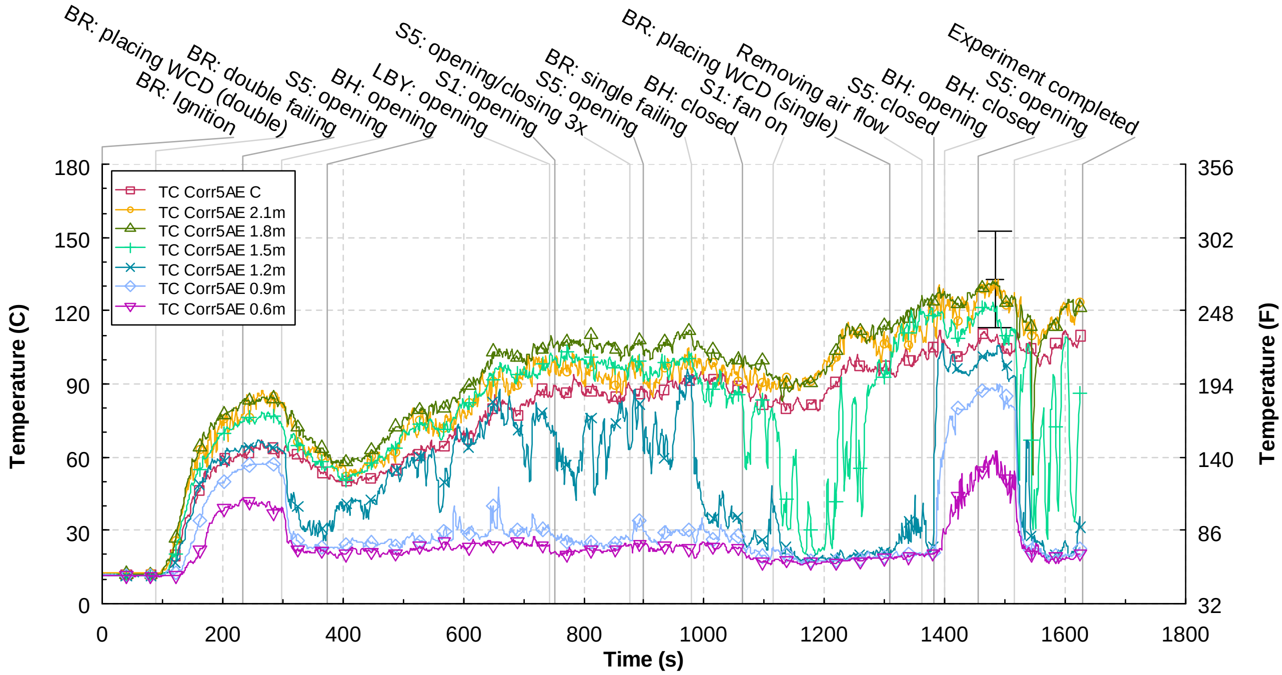



**Figure 9.4-57. Temperature versus time for the 5A hall thermocouple tree, Experiment 5E**

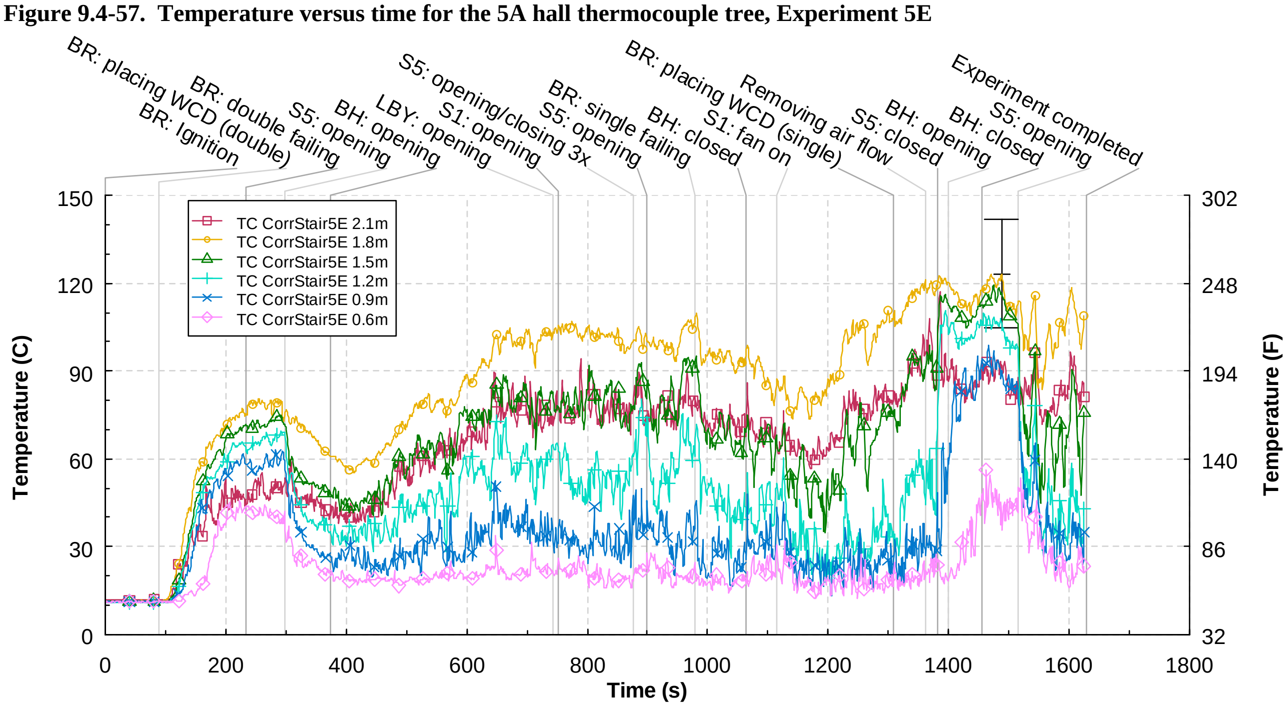



**Figure 9.4-58. Temperature versus time for the 5th floor stair hall thermocouple tree, Experiment 5E**

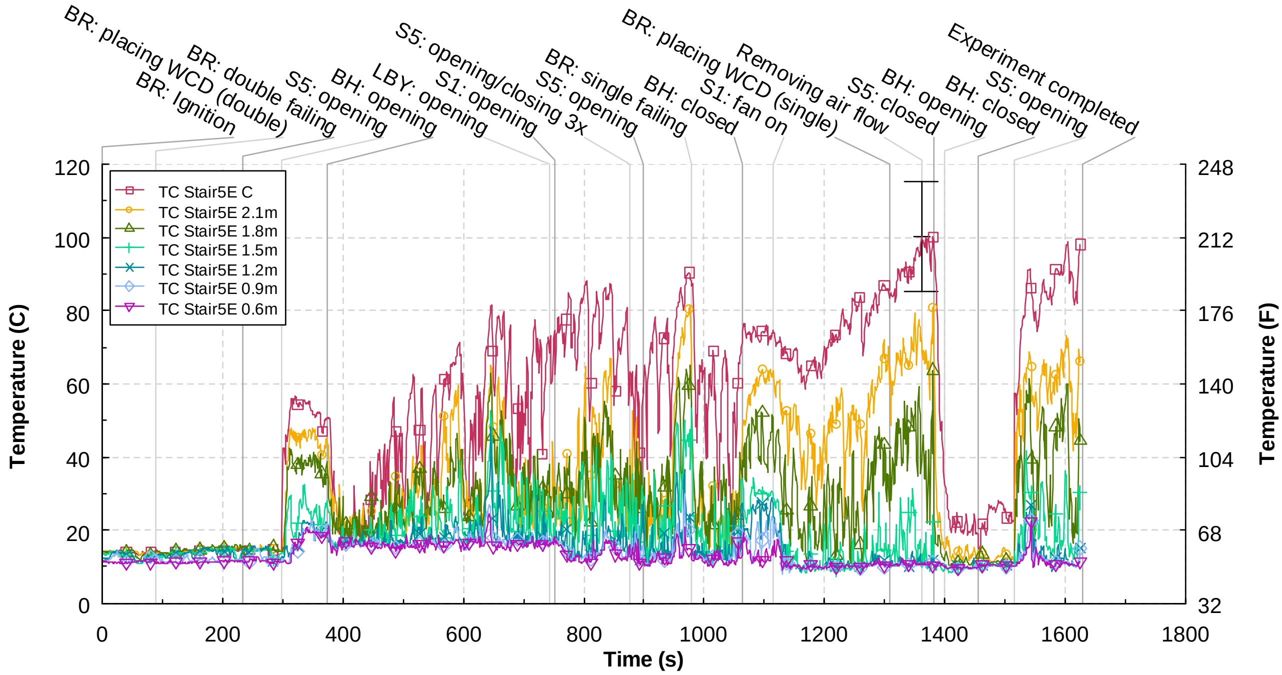



**Figure 9.4-59. Temperature versus time for the 5th floor stairwell thermocouple tree, Experiment 5E**

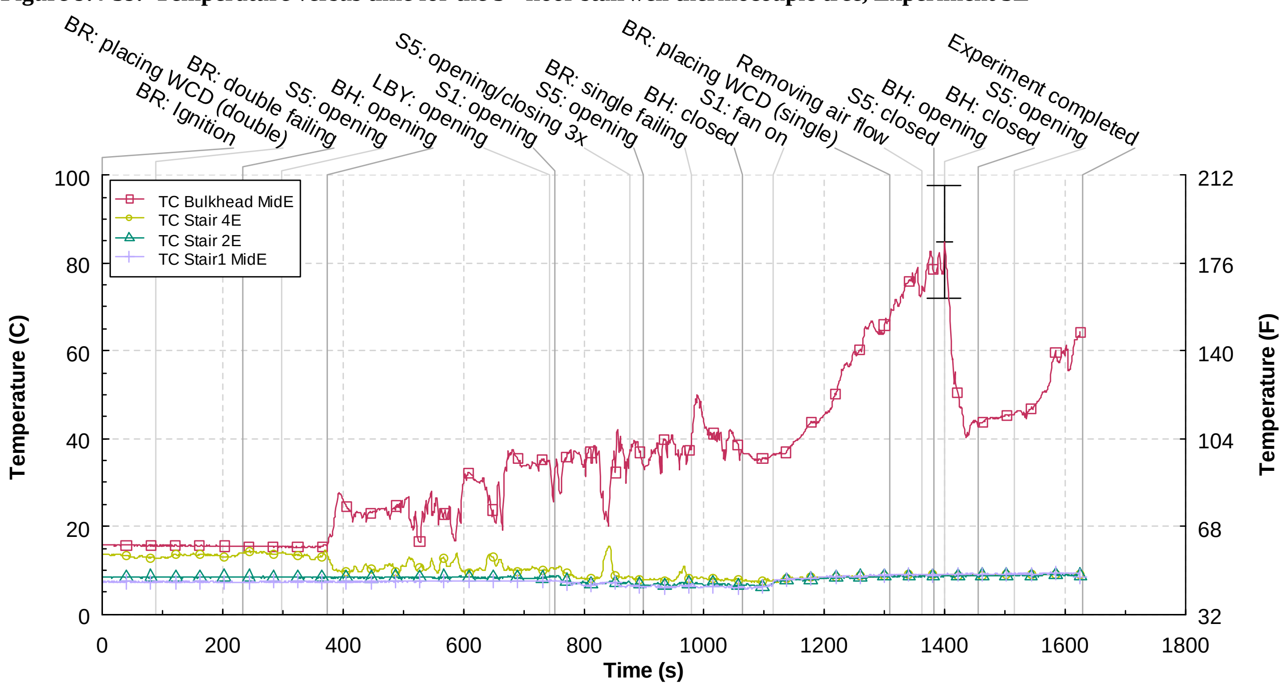



**Figure 9.4-60. Temperature versus time for the stair thermocouples, Experiment 5E**

### 9.4.6.2 Pressures

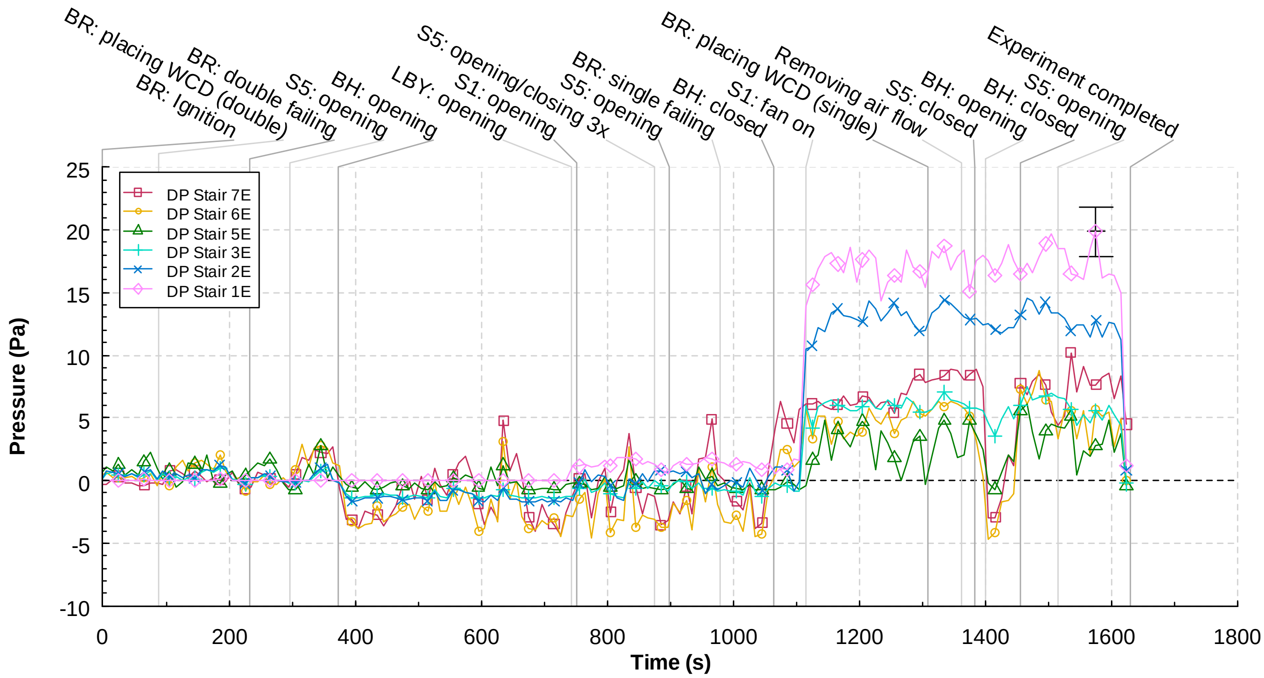



**Figure 9.4-61. Differential pressure versus time for the stairwell bi-directional probes, Experiment 5E**

### 9.4.6.3 Velocities

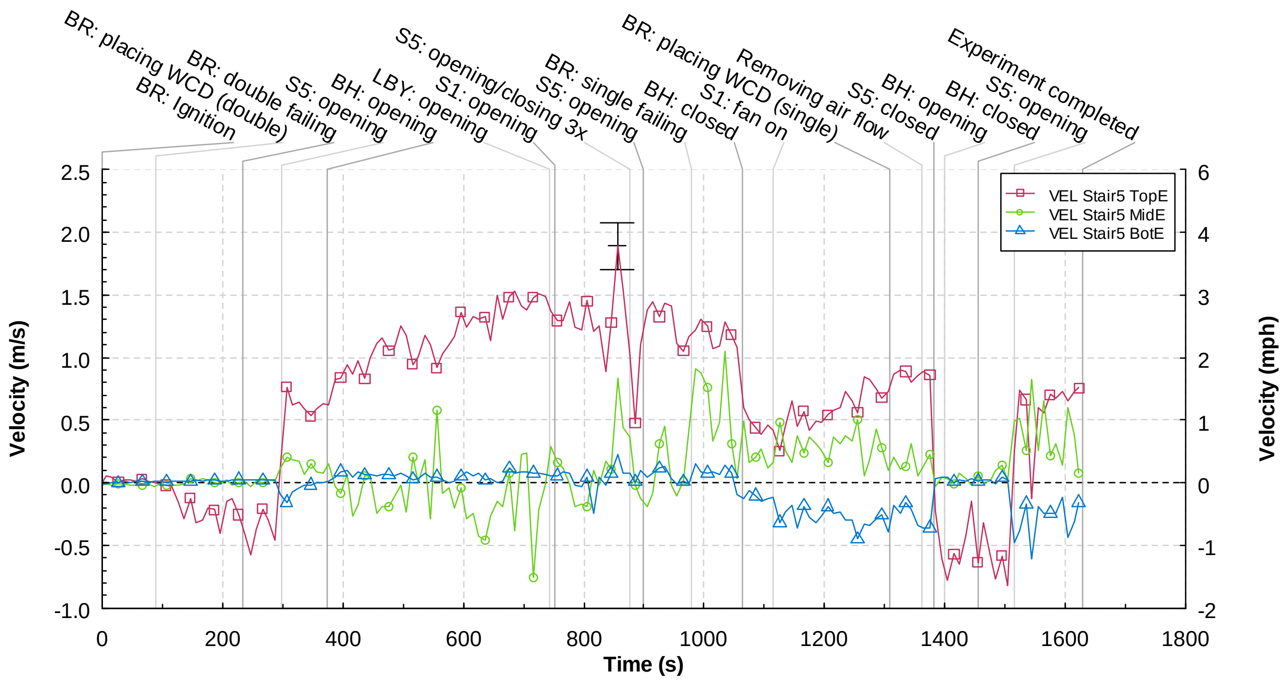



**Figure 9.4-62. Velocity versus time for the 5th floor stairwell bi-directional probes, Experiment 5E**

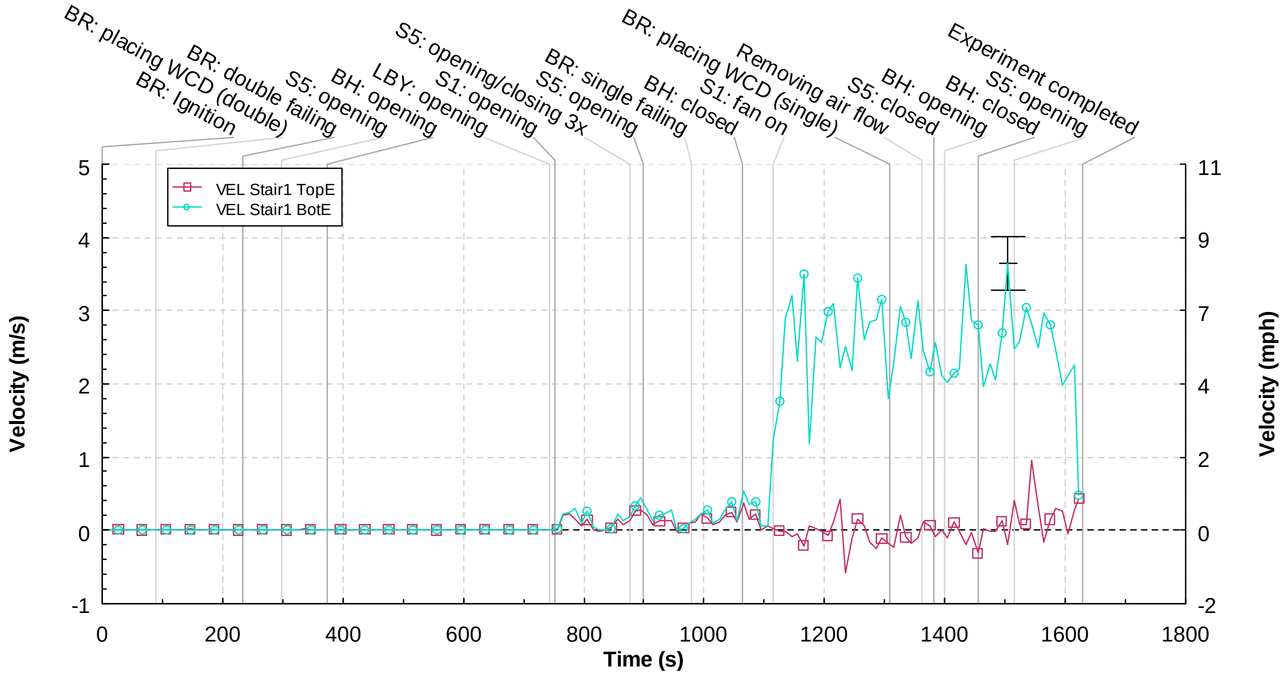



**Figure 9.4-63. Velocity versus time for the 1st floor stairwell bi-directional probes, Experiment 5E**

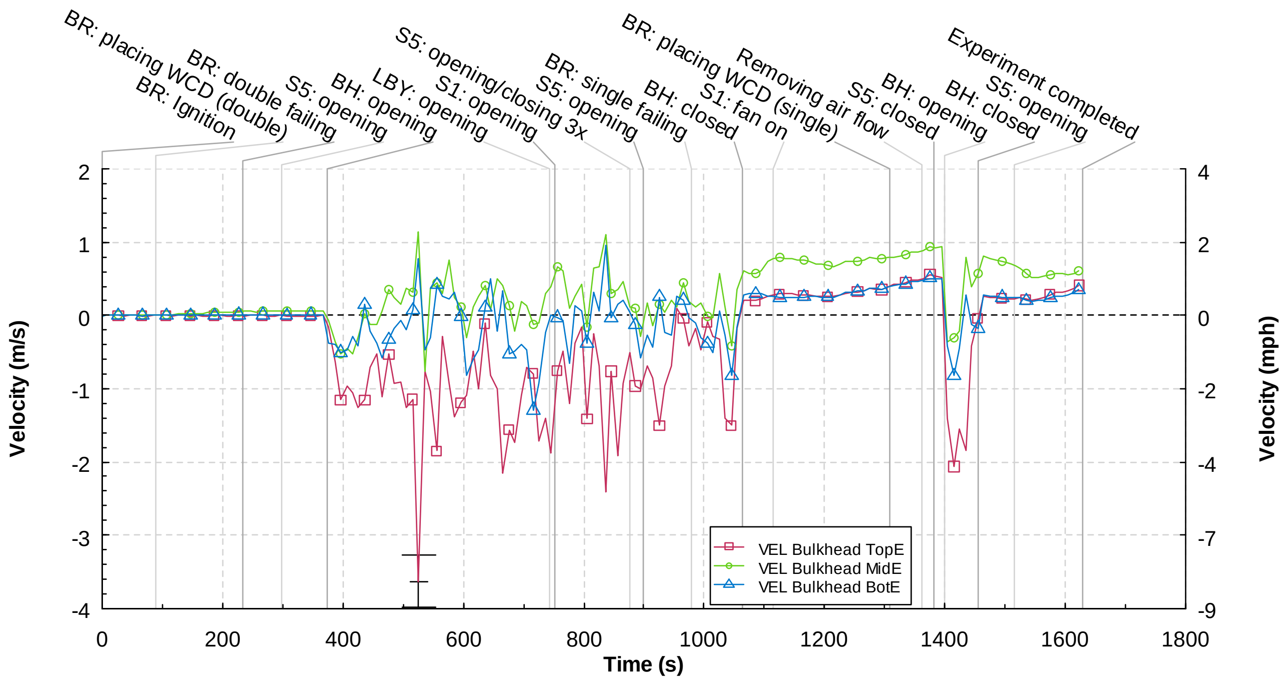



**Figure 9.4-64. Velocity versus time for the bulkhead bi-directional probes, Experiment 5E**

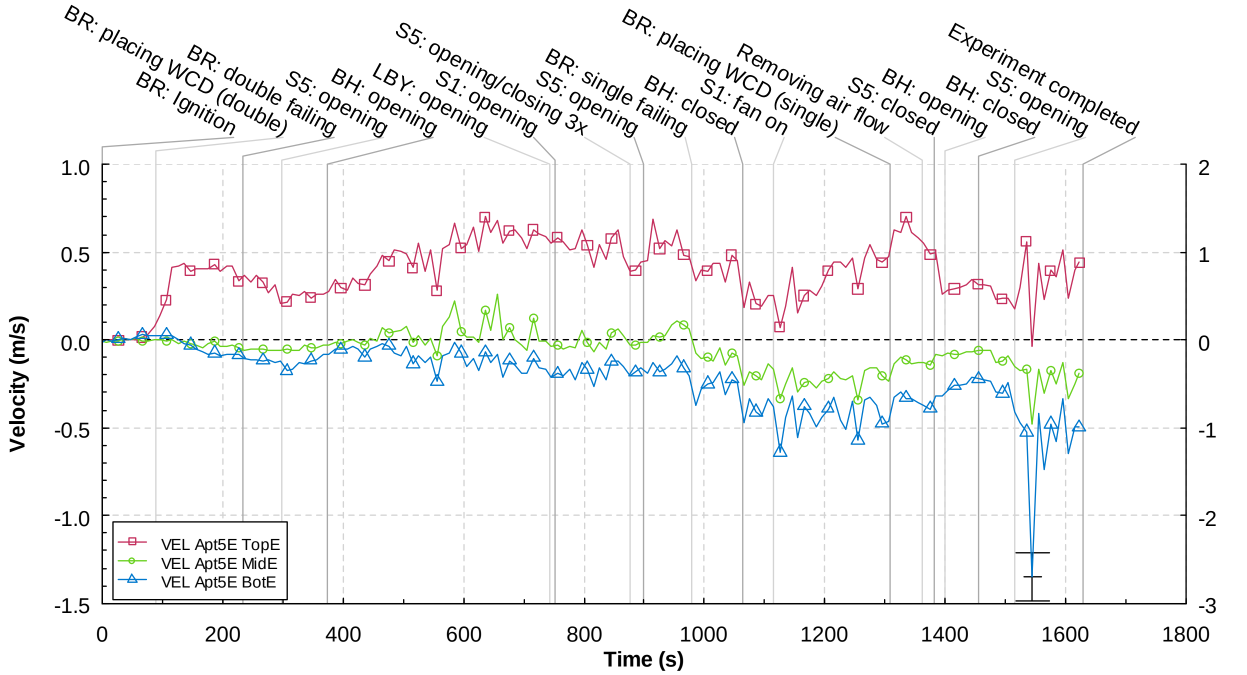



**Figure 9.4-65. Velocity versus time for the apartment 5E doorway bi-directional probes, Experiment 5E**

## 9.4.7 Experiment 5E2

### 9.4.7.1 Temperatures

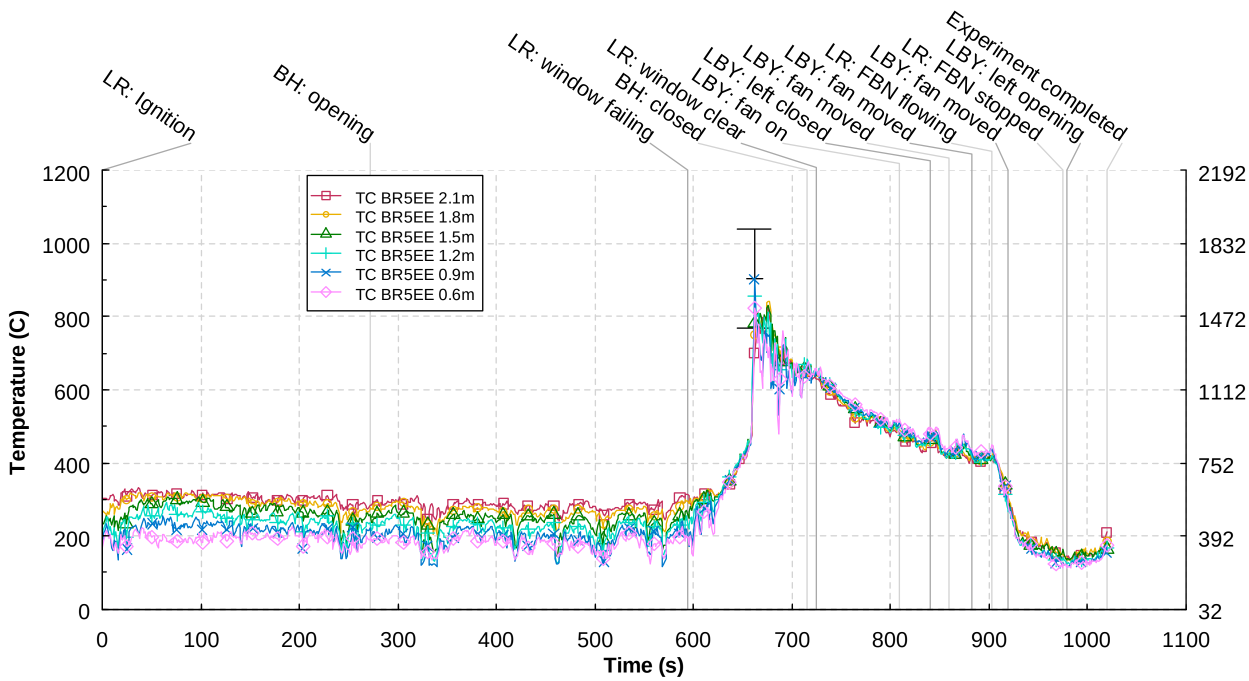



**Figure 9.4-66. Temperature versus time for the 5E2 bedroom thermocouple tree, Experiment 5E2**

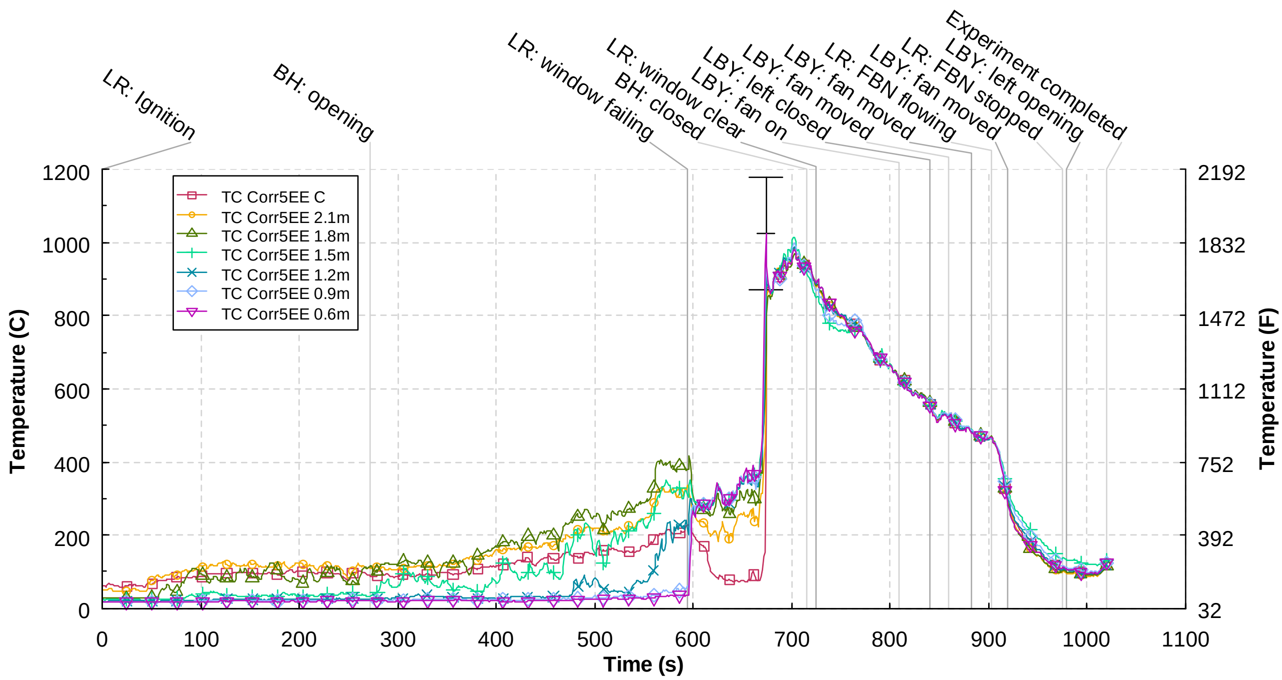



**Figure 9.4-67. Temperature versus time for the 5E2 hall thermocouple tree, Experiment 5E2**

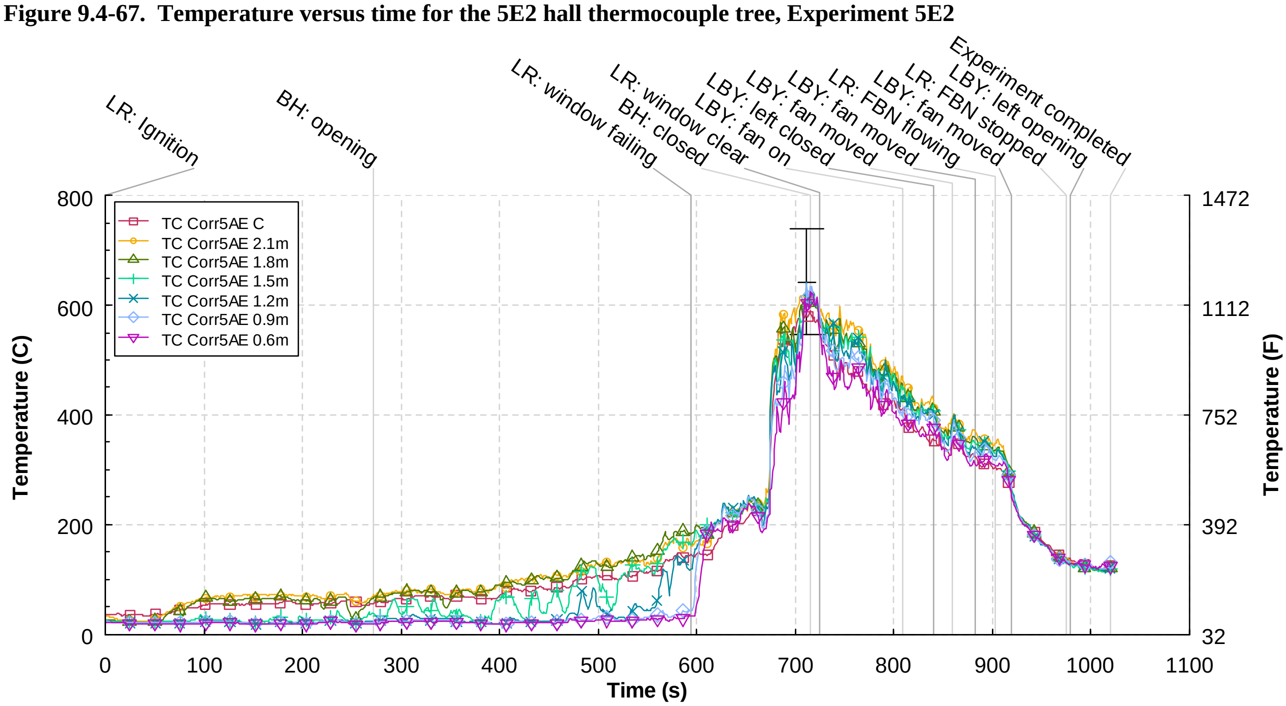



**Figure 9.4-68. Temperature versus time for the 5A hall thermocouple tree, Experiment 5E2**

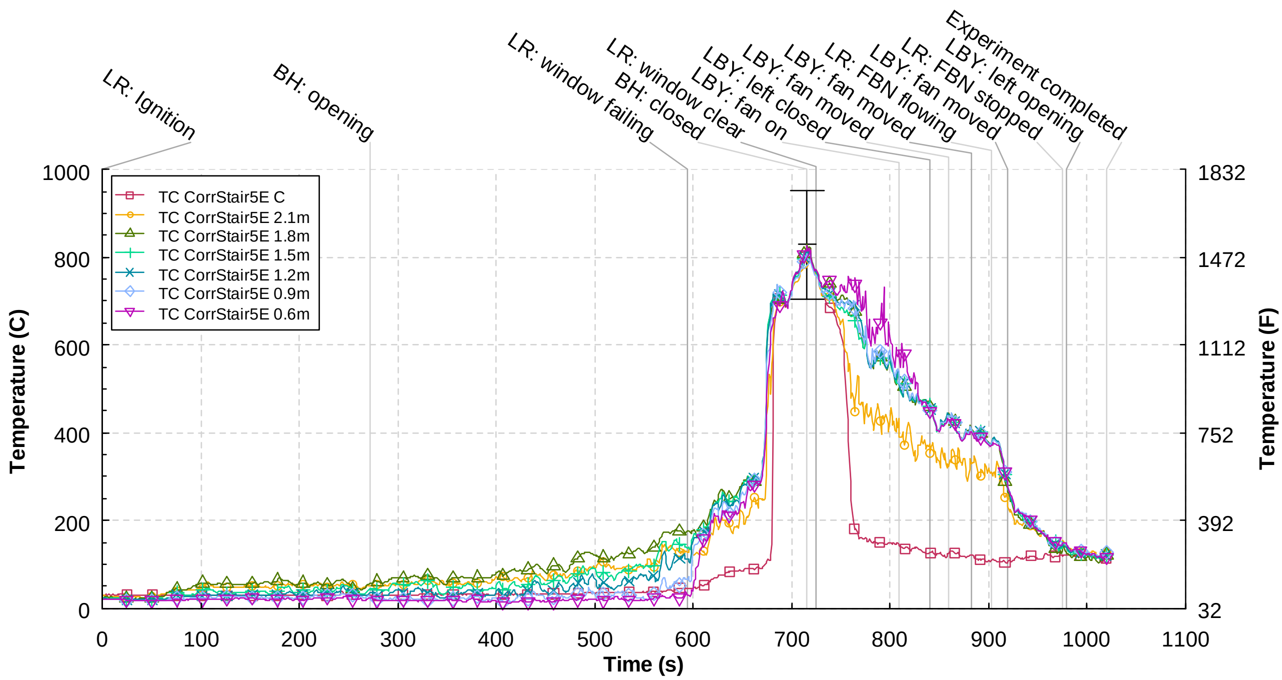



**Figure 9.4-69. Temperature versus time for the 5th floor stair hall thermocouple tree, Experiment 5E2**

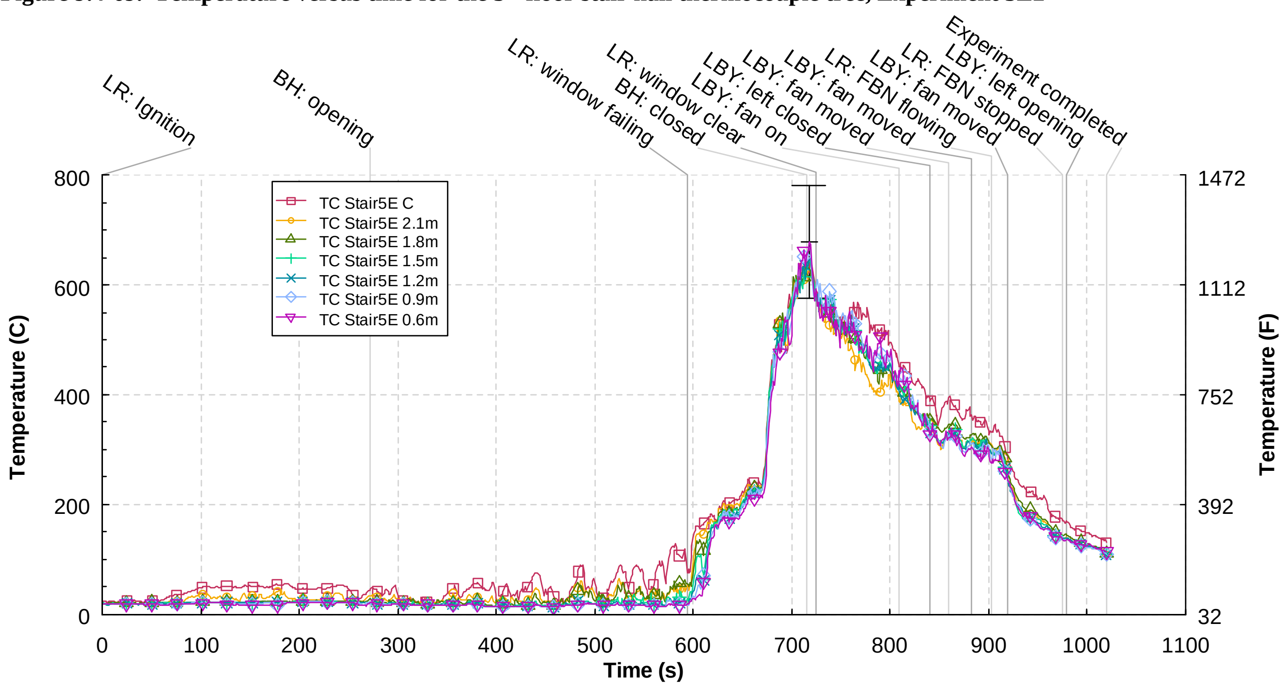



**Figure 9.4-70. Temperature versus time for the 5th floor stairwell thermocouple tree, Experiment 5E2**

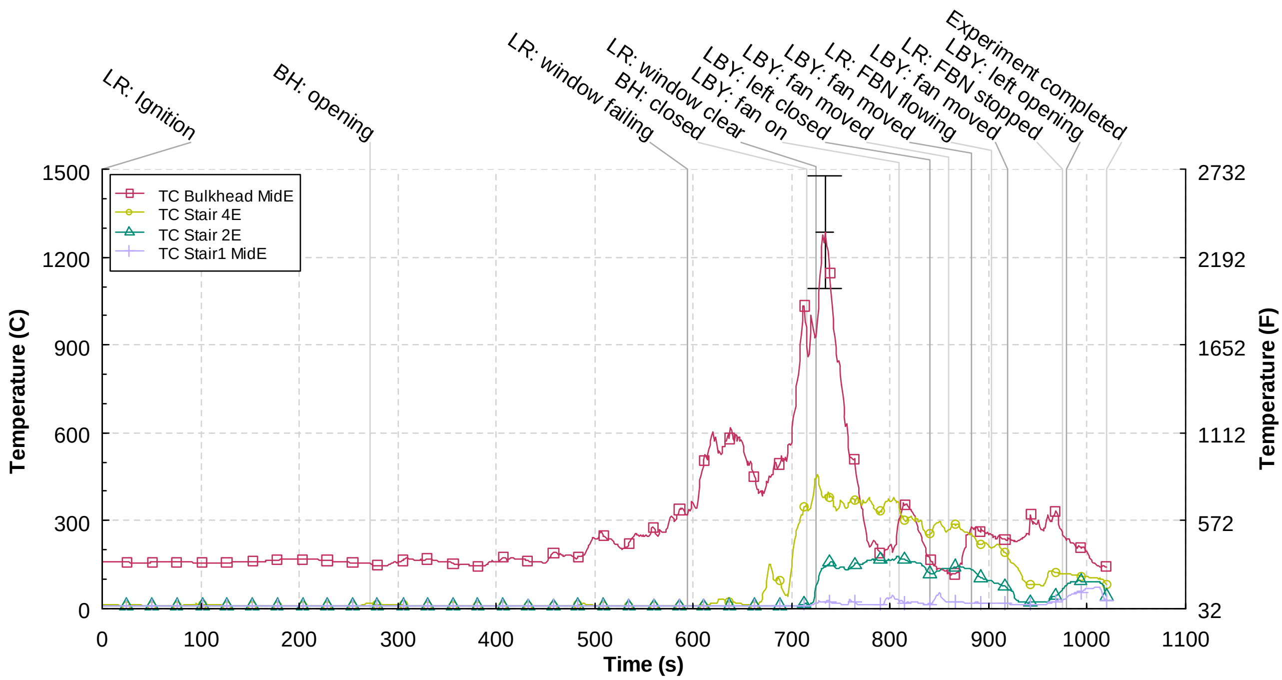



**Figure 9.4-71. Temperature versus time for the stair thermocouples, Experiment 5E2**

## 9.4.7.2 Pressures

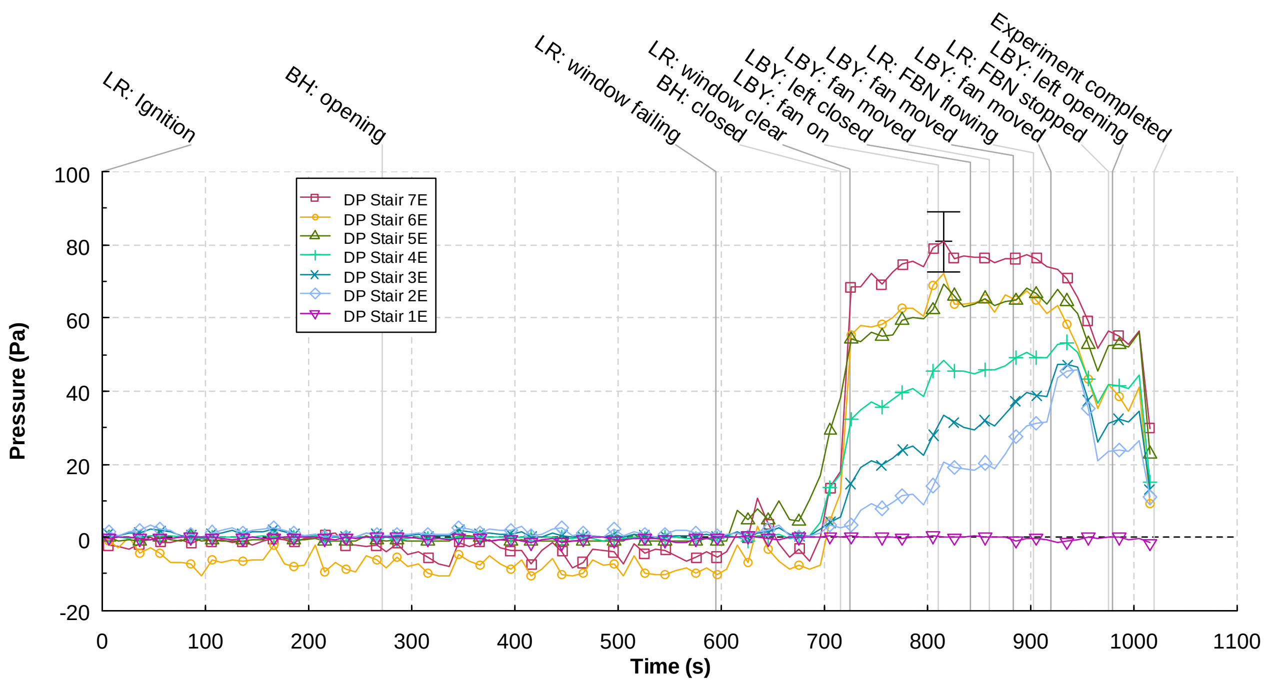



**Figure 9.4-72. Differential pressure versus time for the stairwell bi-directional probes, Experiment 5E2**

### 9.4.7.3 Velocities

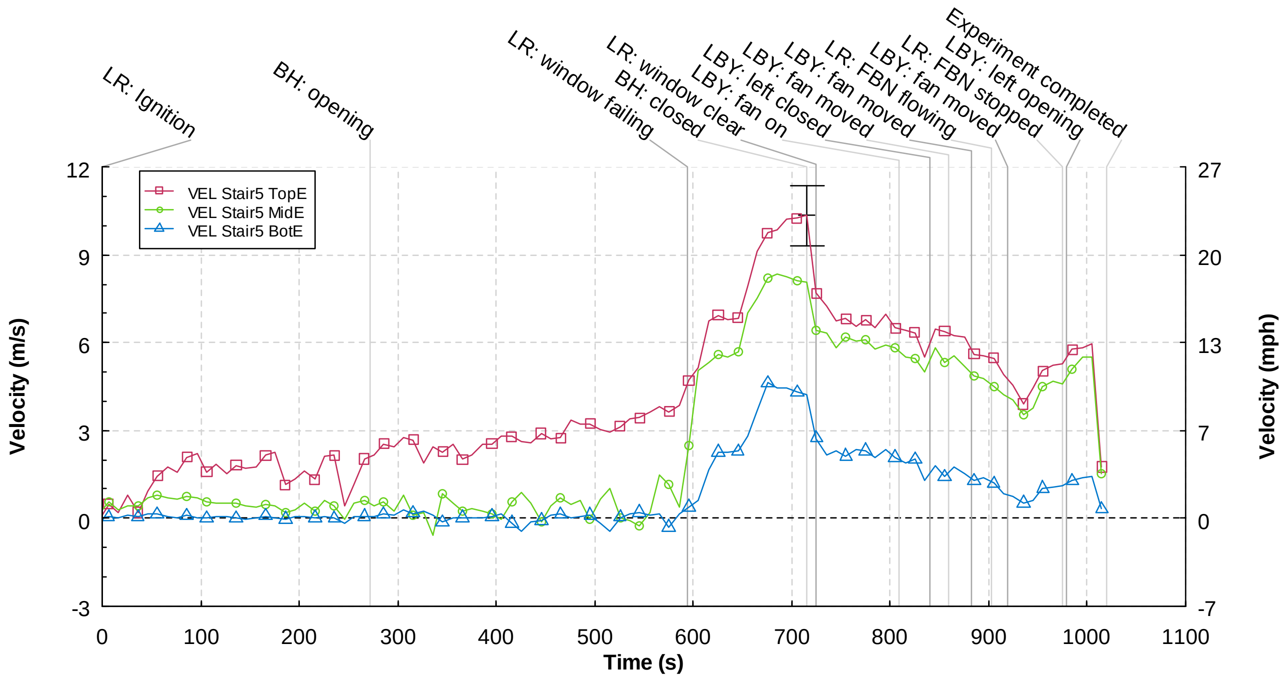



**Figure 9.4-73. Velocity versus time for the 5th floor stairwell bi-directional probes, Experiment 5E2**

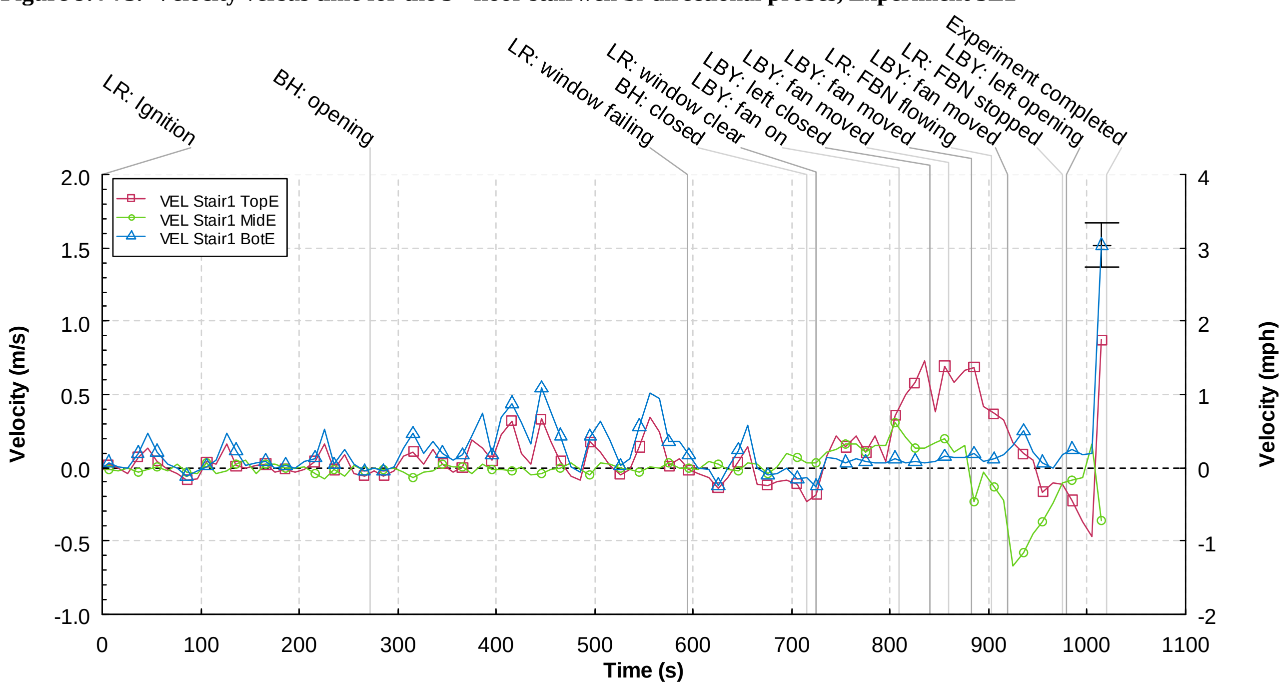



**Figure 9.4-74. Velocity versus time for the 1st floor stairwell bi-directional probes, Experiment 5E2**

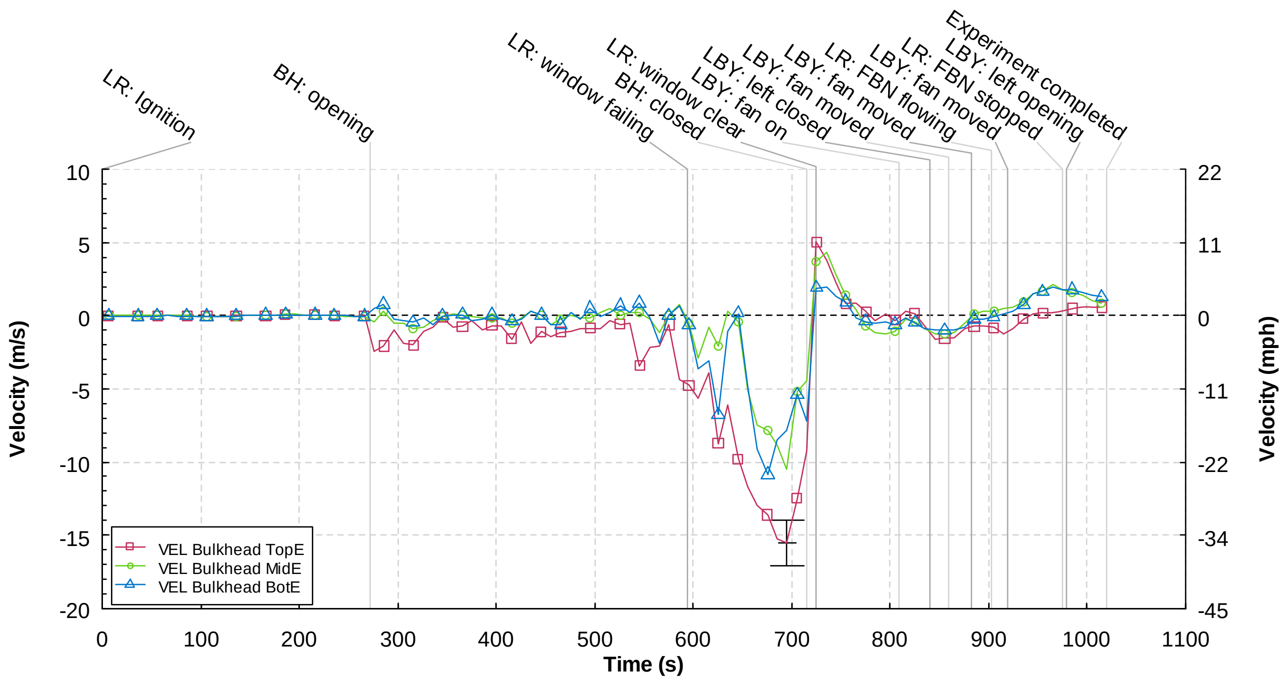



**Figure 9.4-75. Velocity versus time for the bulkhead bi-directional probes, Experiment 5E2**

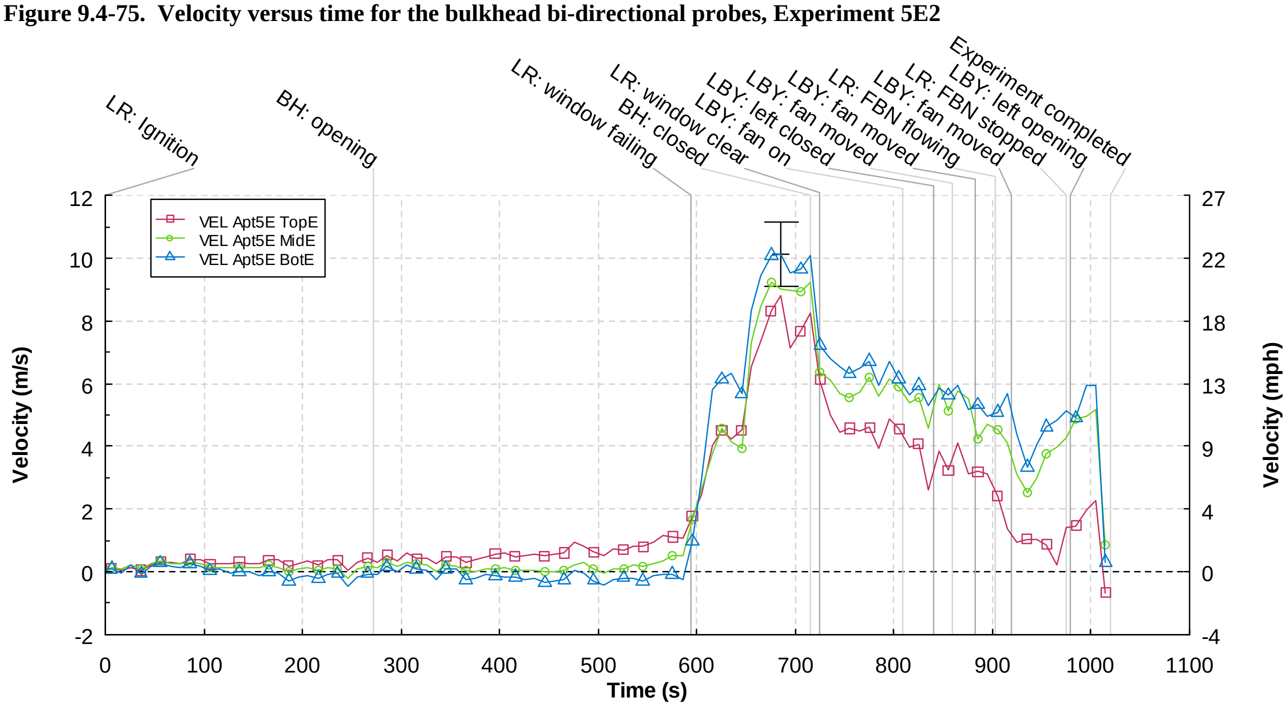



**Figure 9.4-76. Velocity versus time for the apartment 5E doorway bi-directional probes, Experiment 5E2**

## 9.4.8 Experiment 5K

### 9.4.8.1 Temperatures

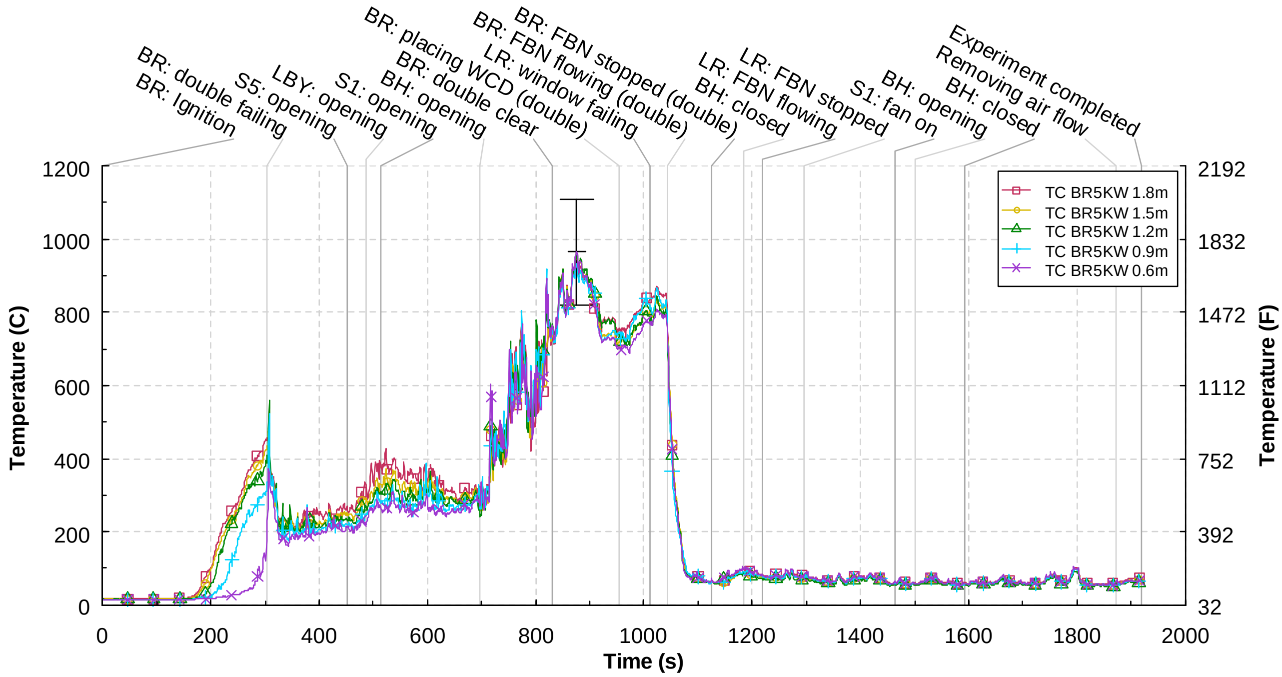



**Figure 9.4-77. Temperature versus time for the 5K bedroom thermocouple tree, Experiment 5K**

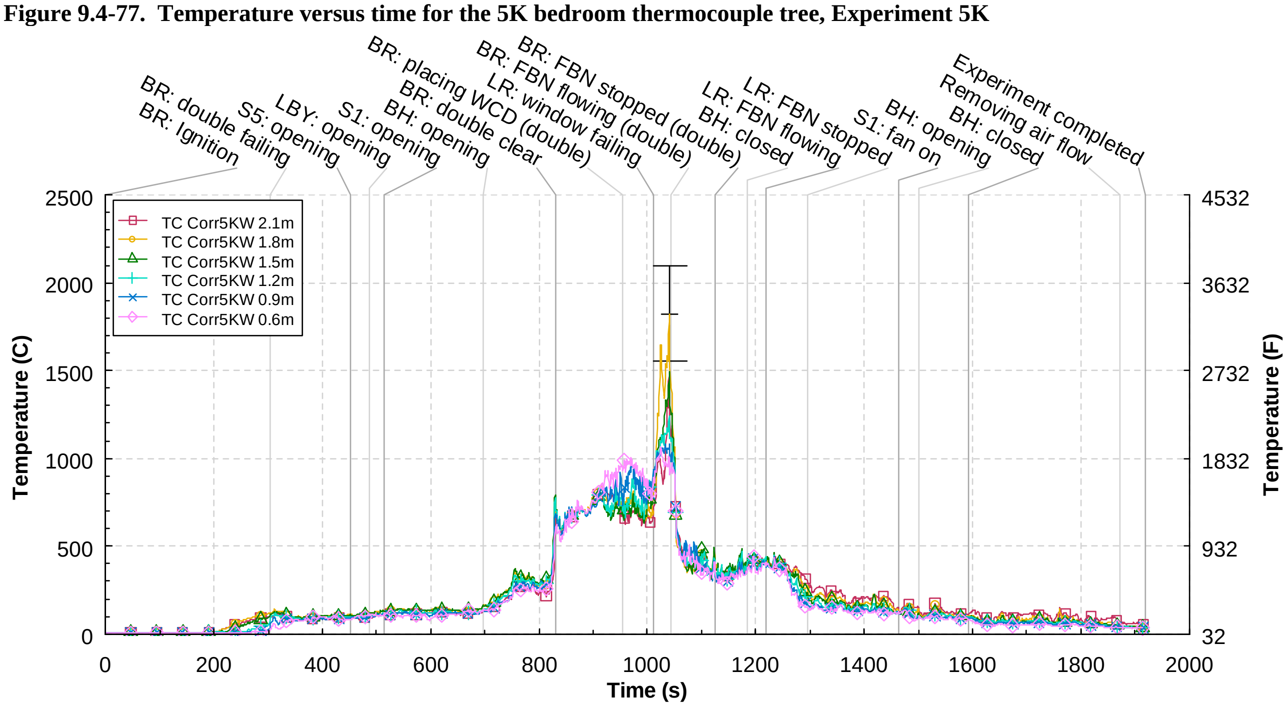



**Figure 9.4-78. Temperature versus time for the 5K hall thermocouple tree, Experiment 5K**

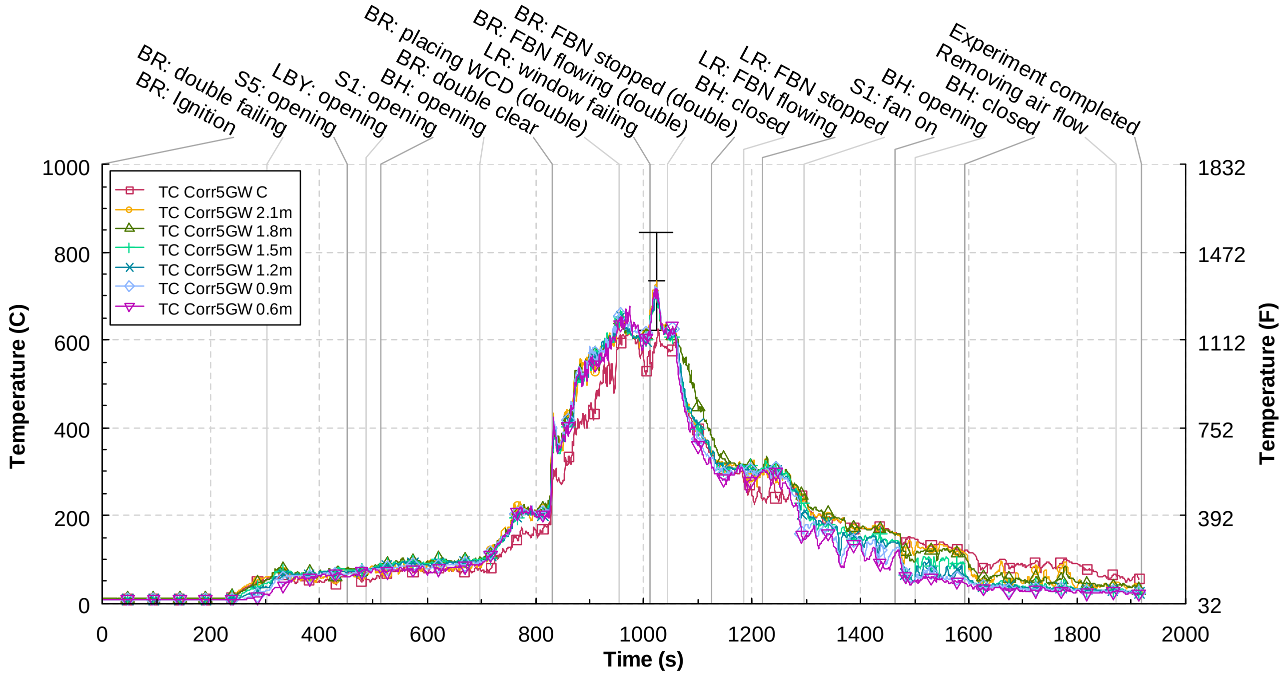



**Figure 9.4-79. Temperature versus time for the 5G hall thermocouple tree, Experiment 5K**

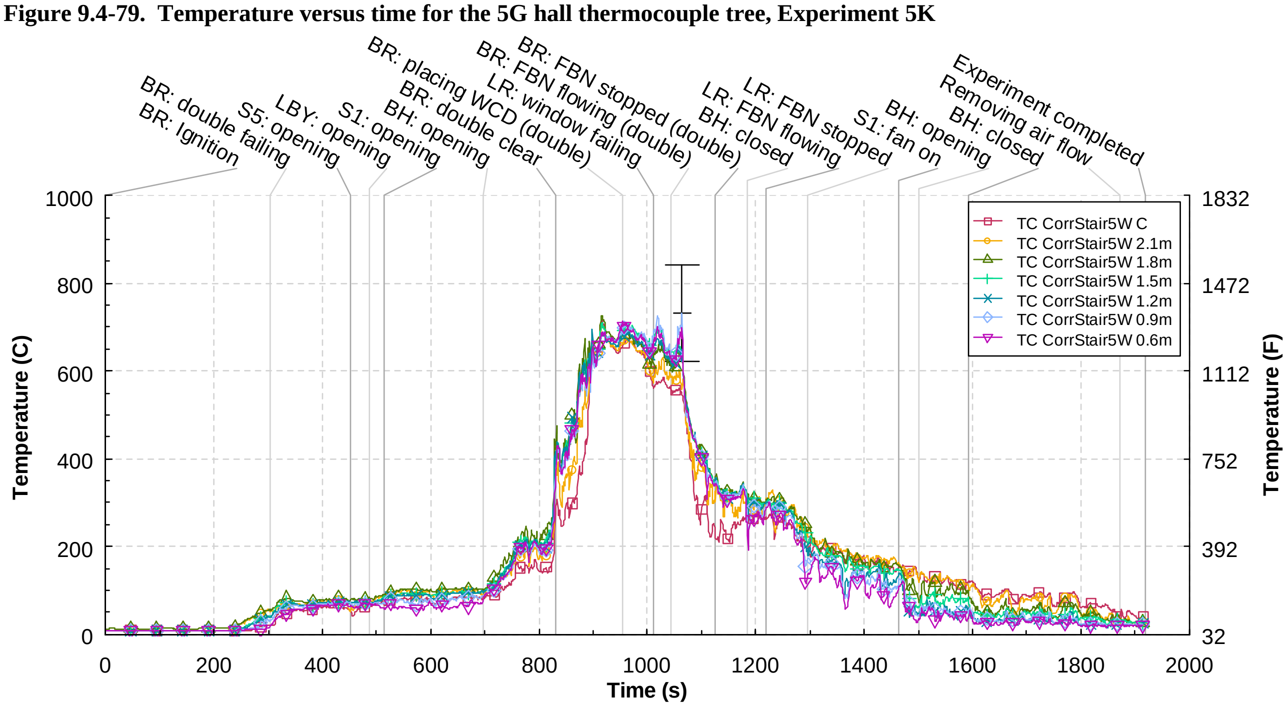



**Figure 9.4-80. Temperature versus time for the 5th floor stair hall thermocouple tree, Experiment 5K**

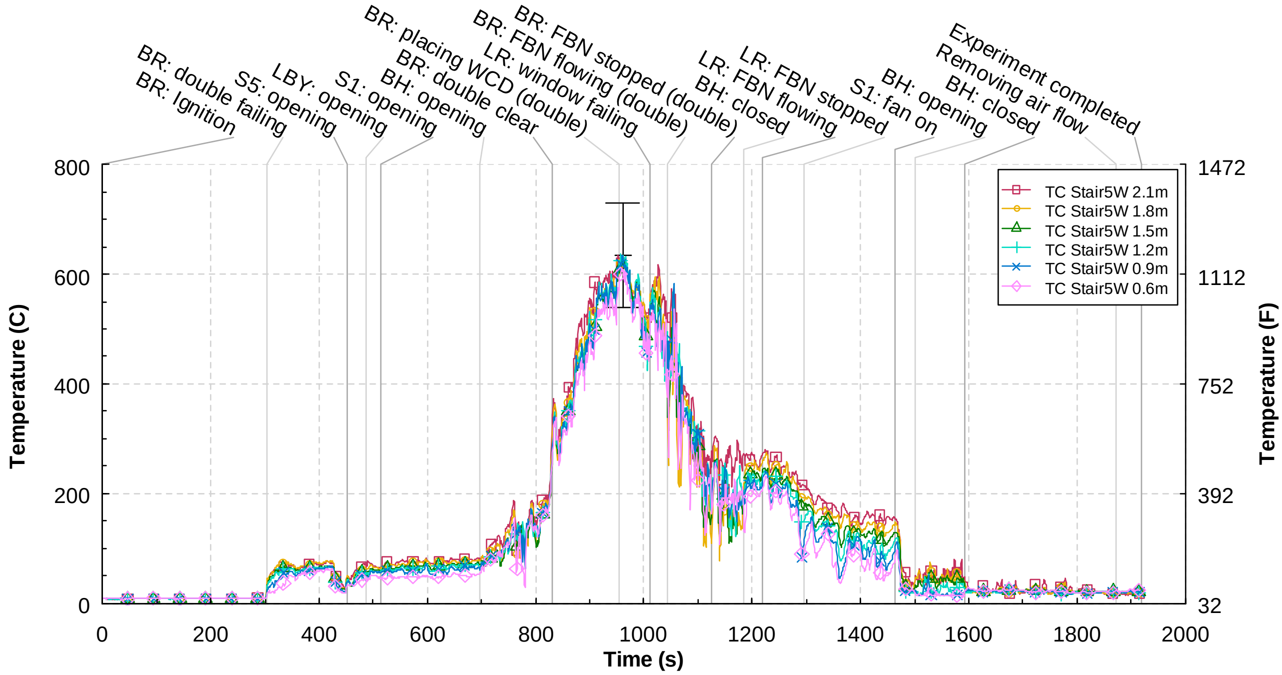



**Figure 9.4-81. Temperature versus time for the 5th floor stairwell thermocouple tree, Experiment 5K**

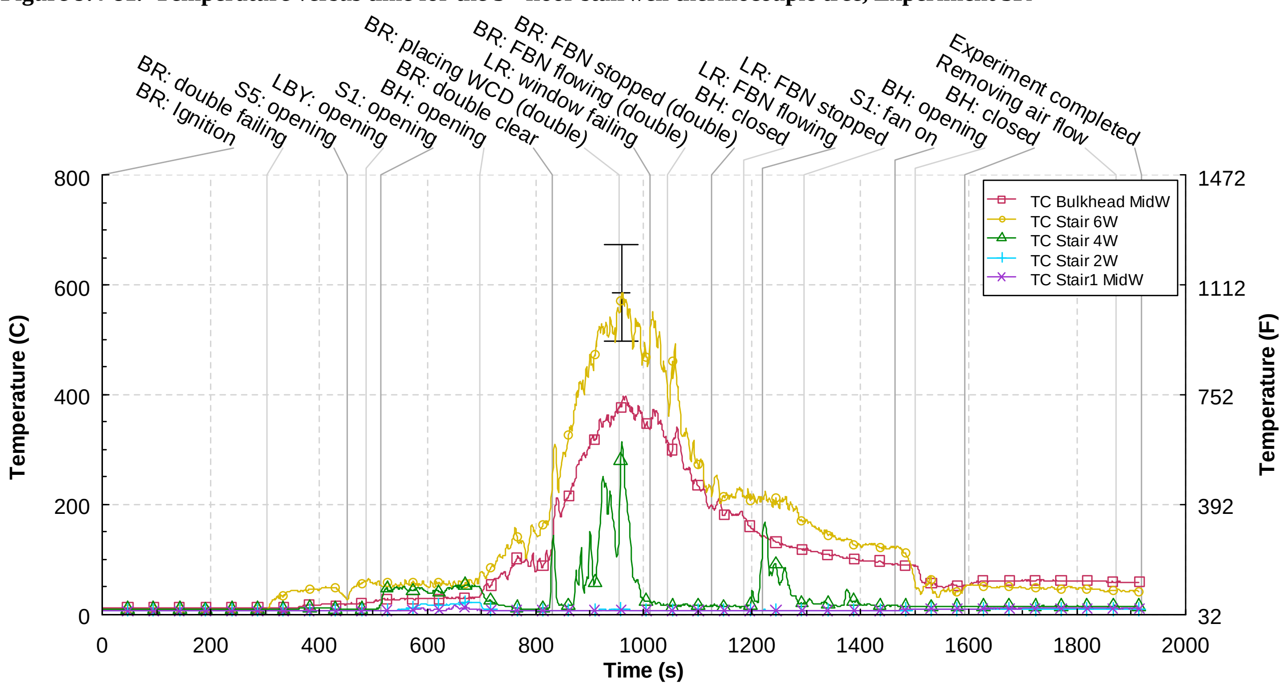



**Figure 9.4-82. Temperature versus time for the stair thermocouples, Experiment 5K**

### 9.4.8.2 Pressures

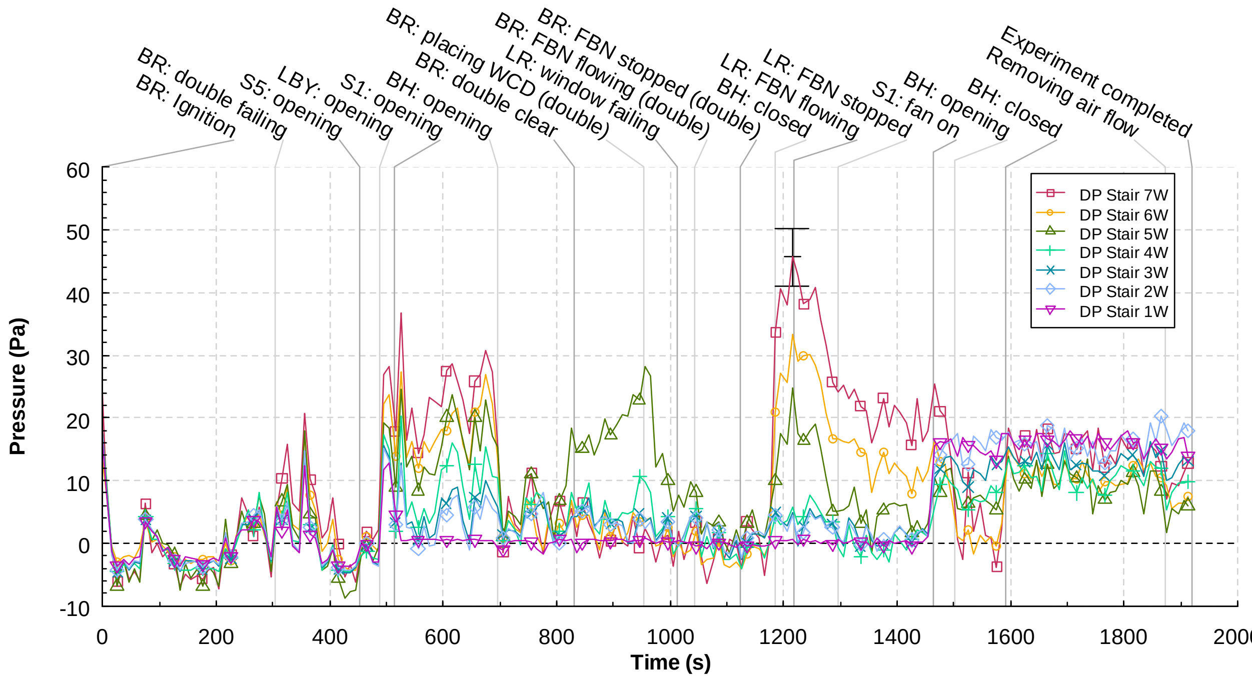



**Figure 9.4-83. Differential pressure versus time for the stairwell bi-directional probes, Experiment 5K**

### 9.4.8.3 Velocities

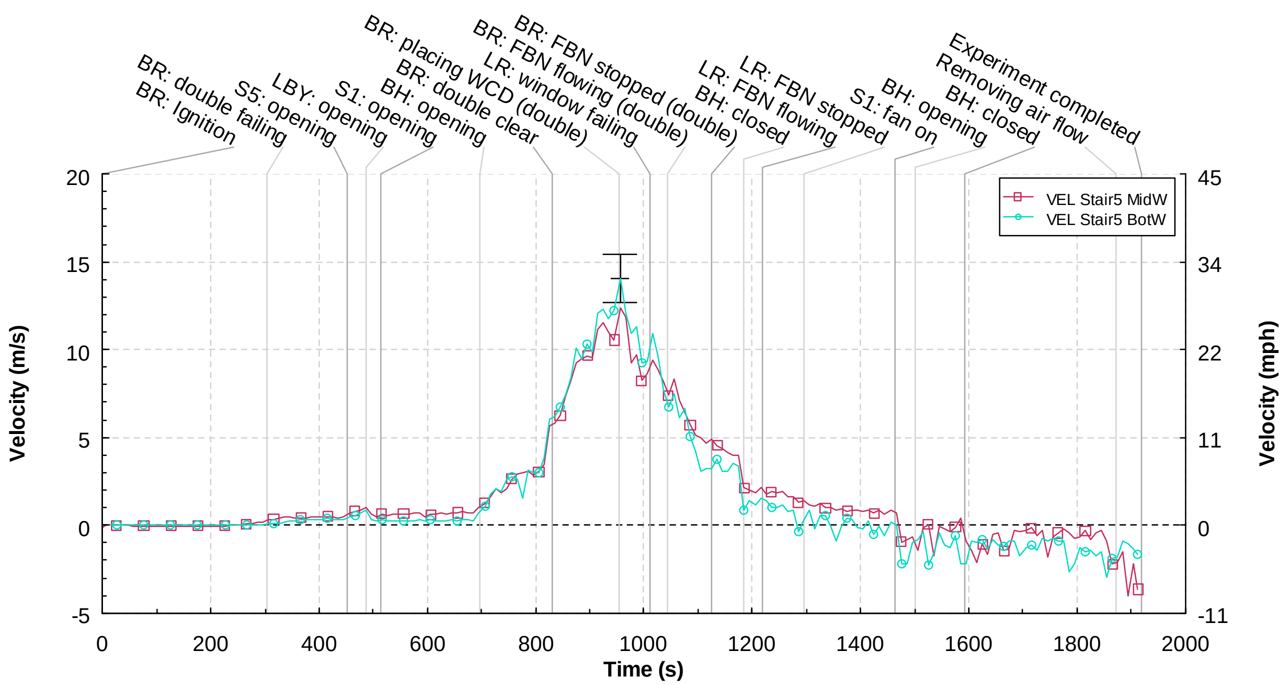



**Figure 9.4-84. Velocity versus time for the 5th floor stairwell bi-directional probes, Experiment 5K**

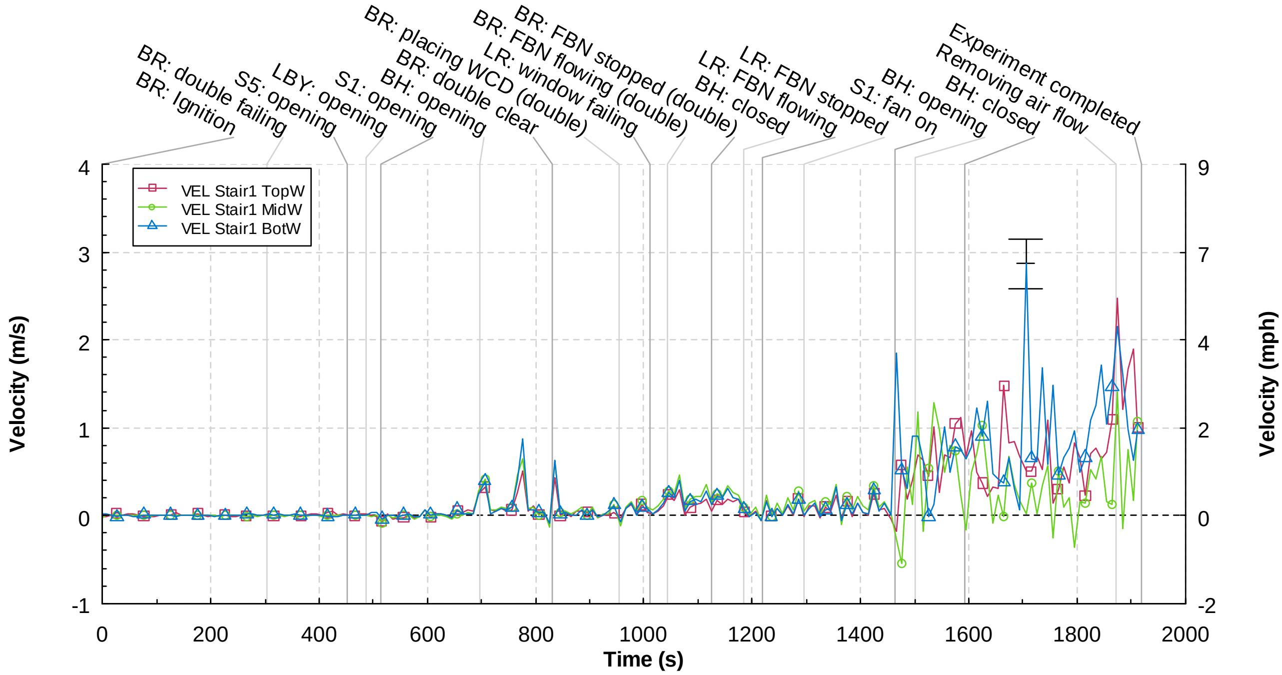



**Figure 9.4-85. Velocity versus time for the 1st floor stairwell bi-directional probes, Experiment 5K**

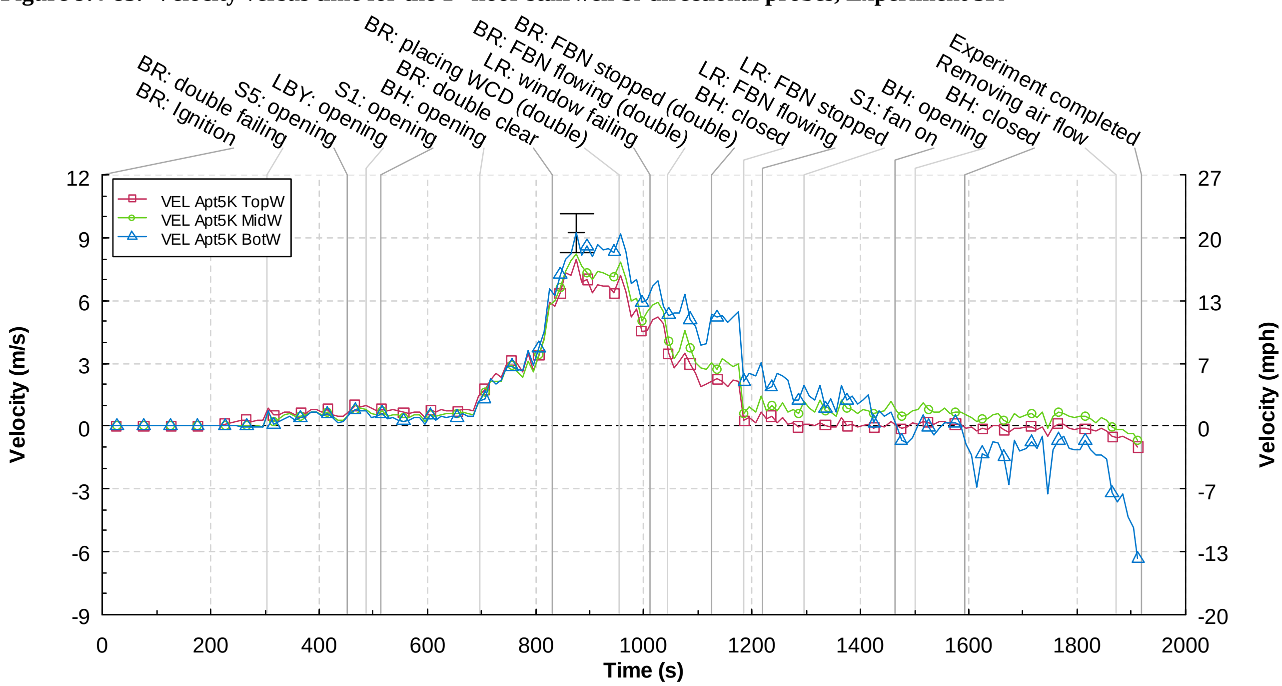



**Figure 9.4-86. Velocity versus time for the apartment 5K doorway bi-directional probes, Experiment 5K**

## 9.4.9 Experiment 5A

### 9.4.9.1 Temperatures

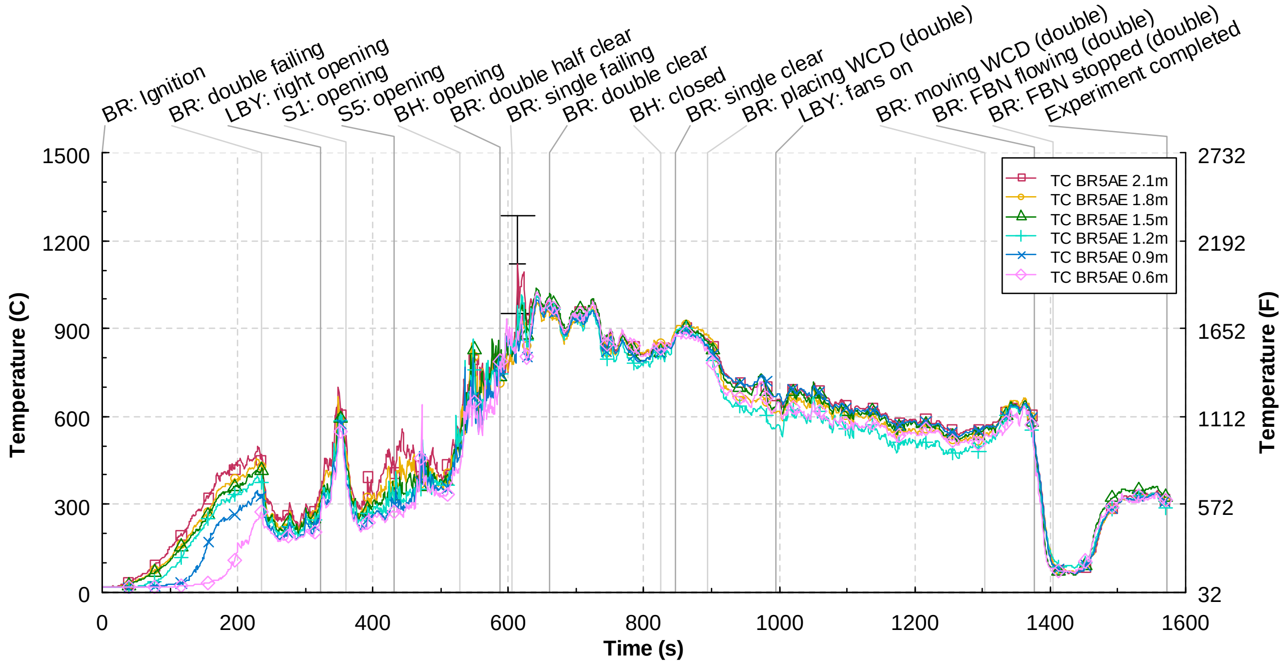



**Figure 9.4-87. Temperature versus time for the 5A bedroom thermocouple tree, Experiment 5A**

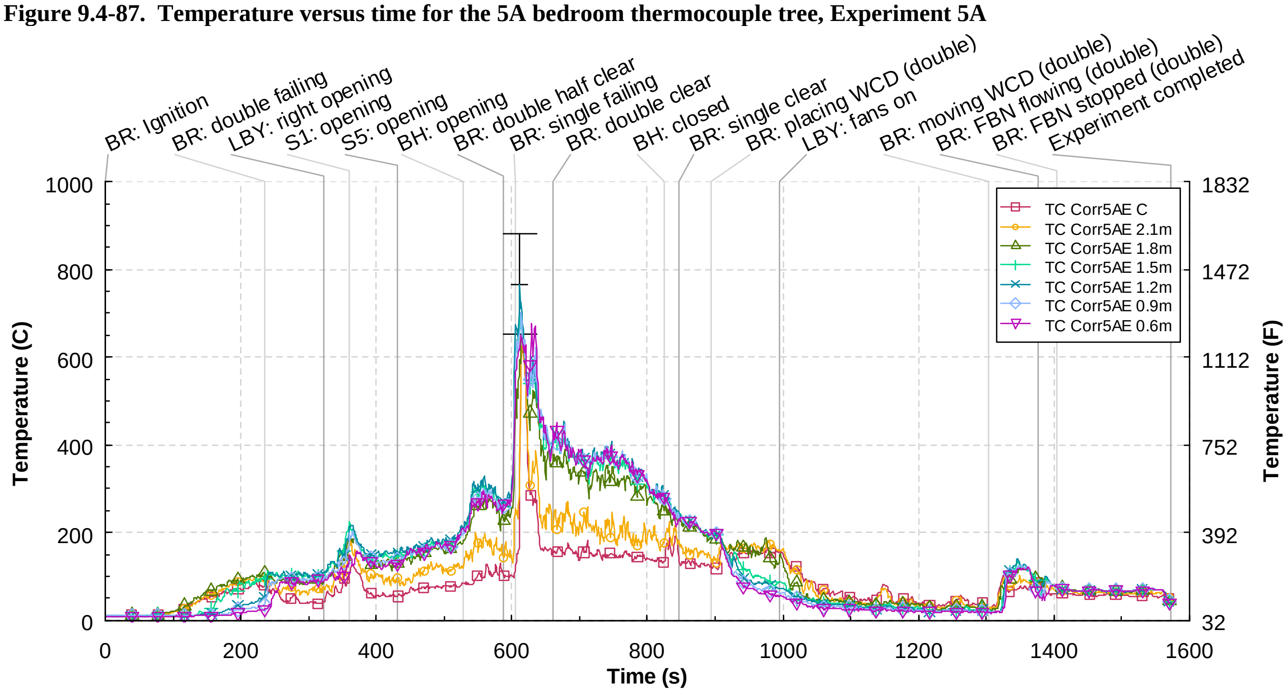



**Figure 9.4-88. Temperature versus time for the 5A hall thermocouple tree, Experiment 5A**

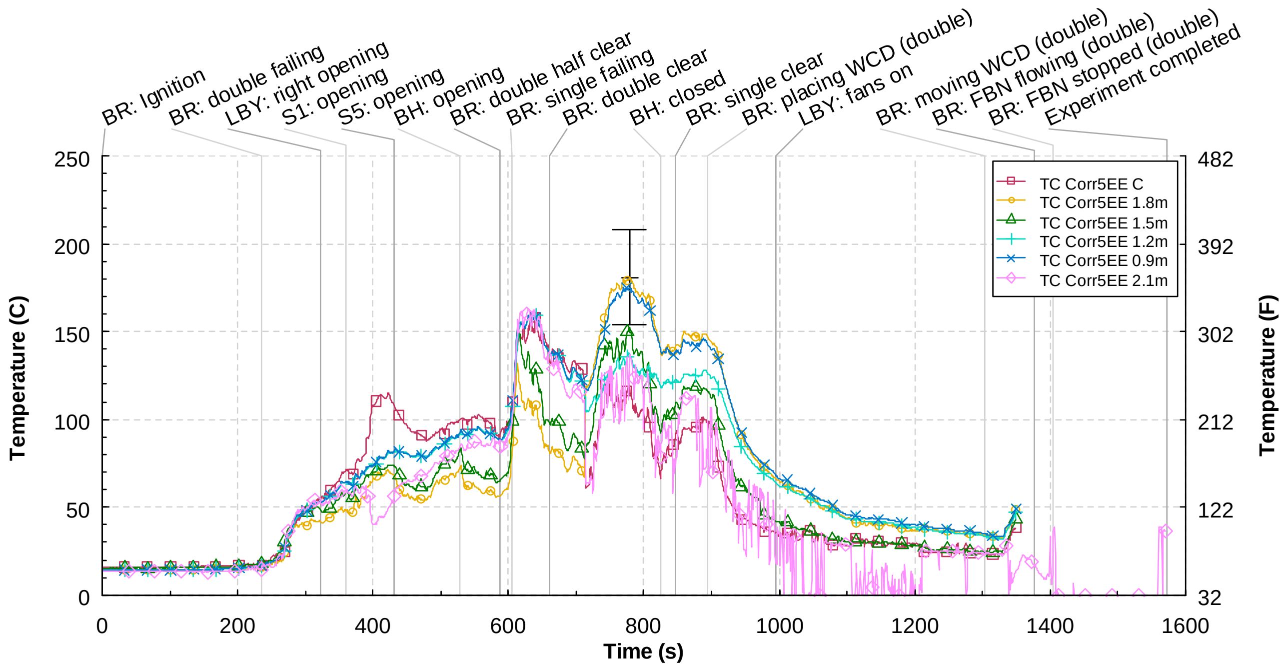



**Figure 9.4-89. Temperature versus time for the 5E hall thermocouple tree, Experiment 5A**

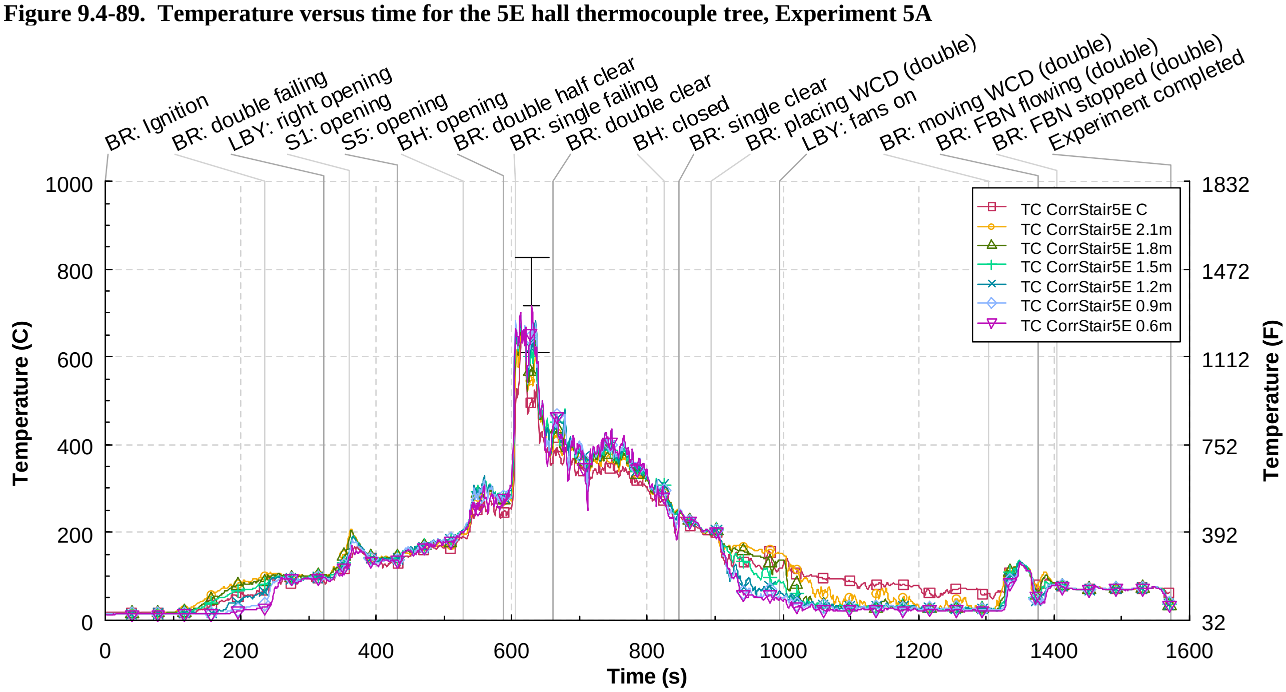



**Figure 9.4-90. Temperature versus time for the 5th floor stair hall thermocouple tree, Experiment 5A**

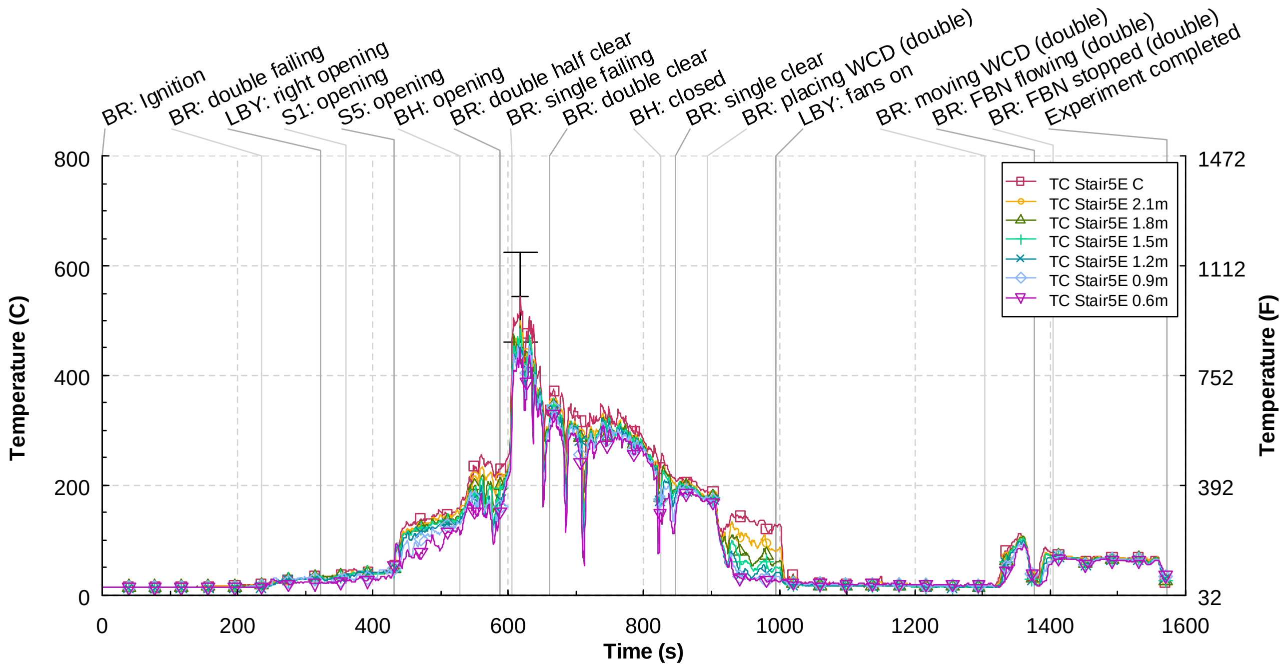



**Figure 9.4-91. Temperature versus time for the 5th floor stairwell thermocouple tree, Experiment 5A**

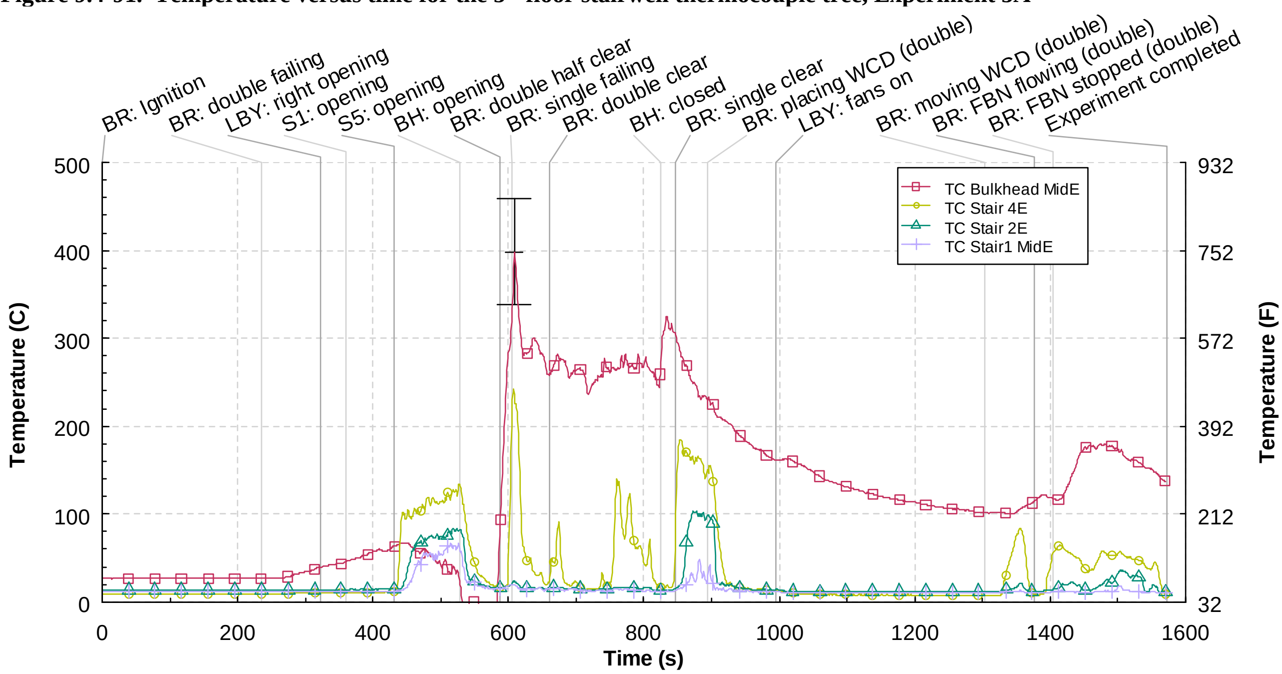



**Figure 9.4-92. Temperature versus time for the stair thermocouples, Experiment 5A**

### 9.4.9.2 Pressures

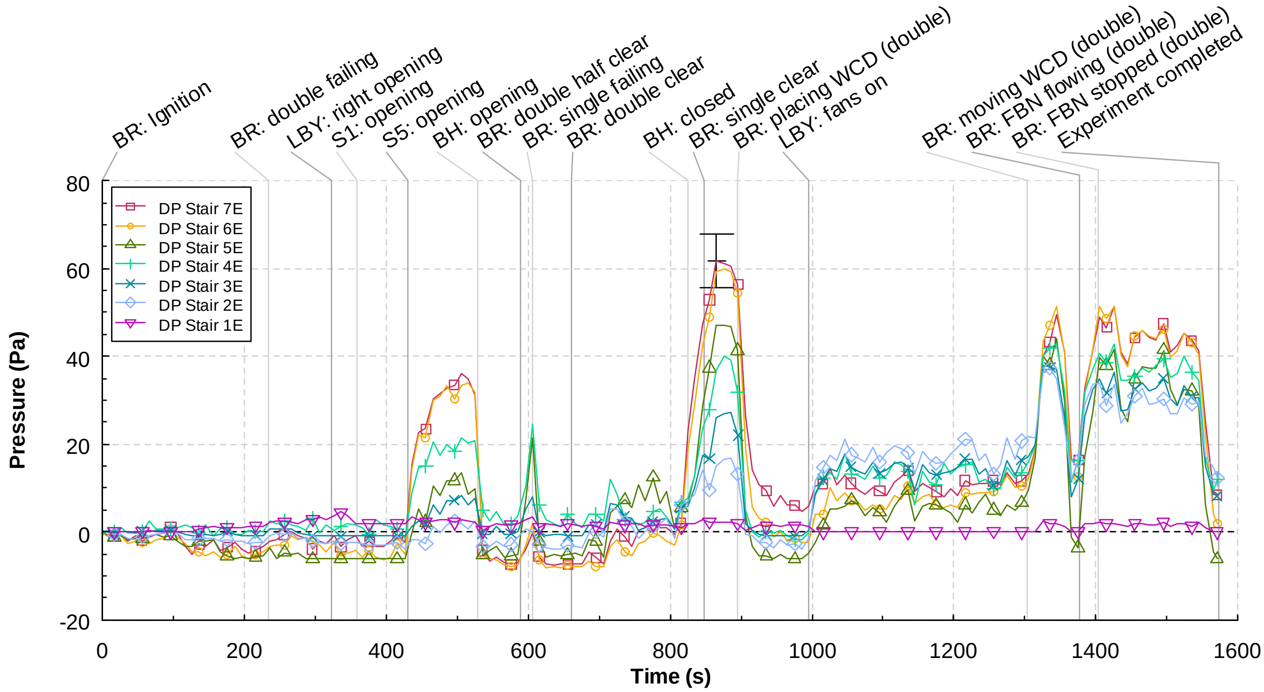



**Figure 9.4-93. Differential pressure versus time for the stairwell bi-directional probes, Experiment 5A**

### 9.4.9.3 Velocities

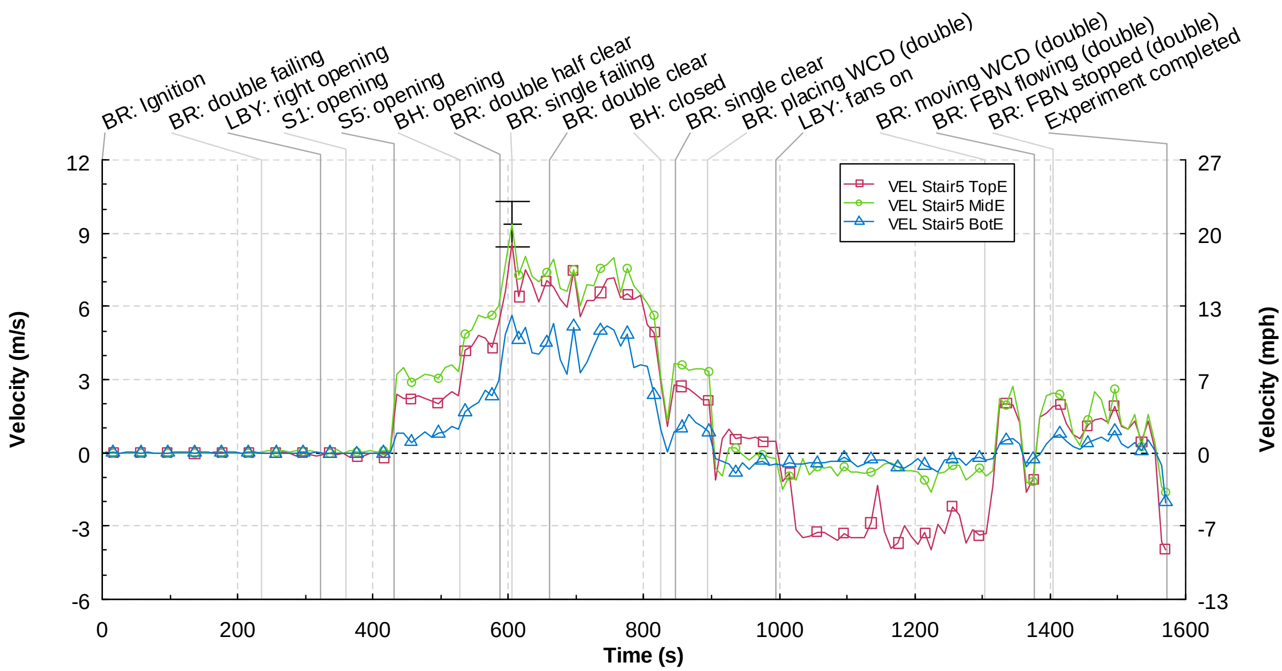



**Figure 9.4-94. Velocity versus time for the 5th floor stairwell bi-directional probes, Experiment 5A**

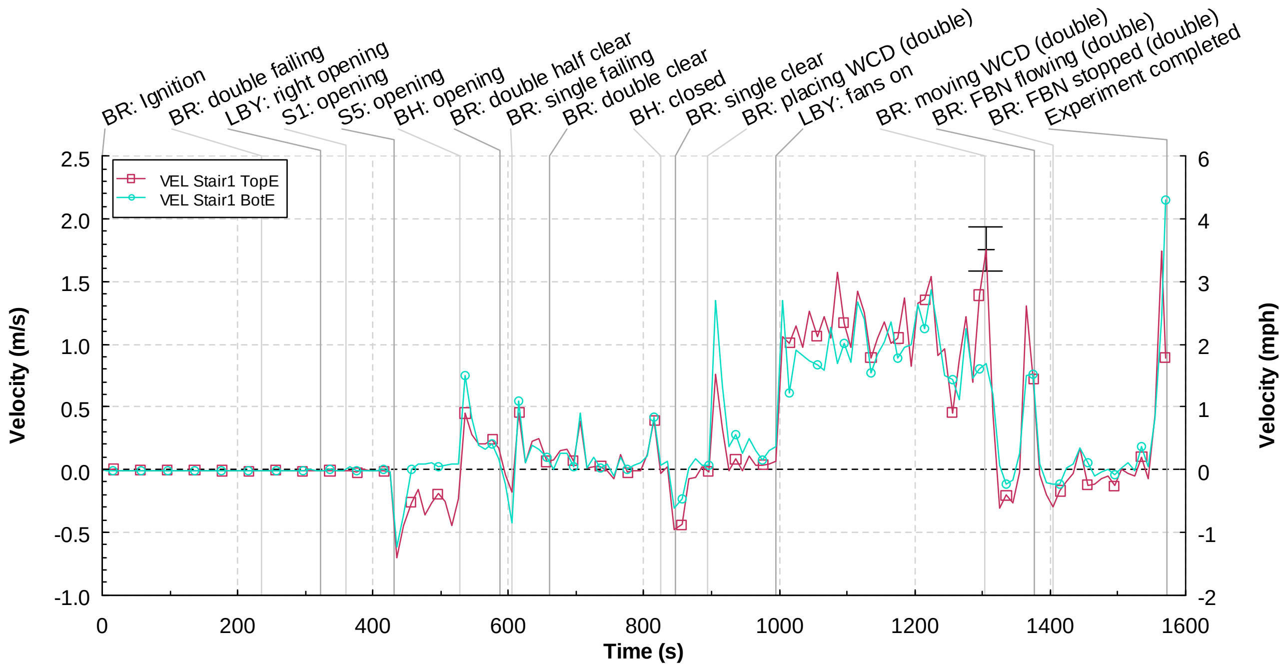



**Figure 9.4-95. Velocity versus time for the 1st floor stairwell bi-directional probes, Experiment 5A**

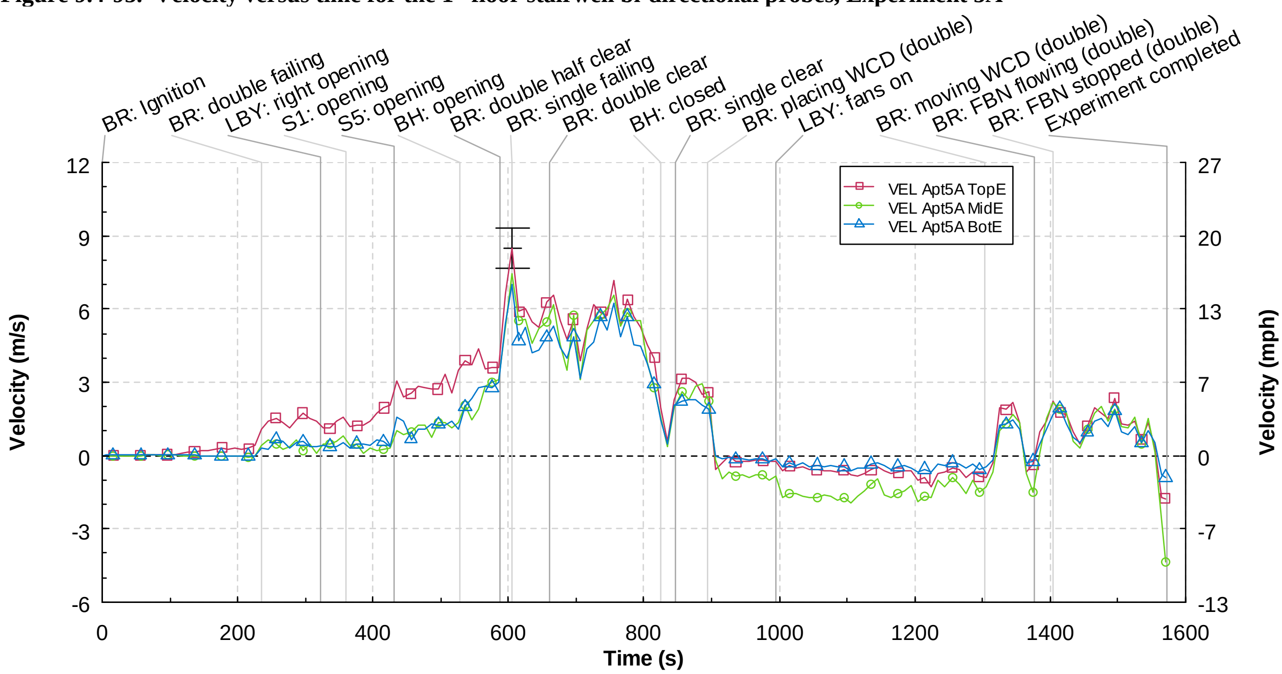



**Figure 9.4-96. Velocity versus time for the apartment 5A doorway bi-directional probes, Experiment 5A**

### 9.4.10 Experiment 5G

### 9.4.10.1 Temperatures

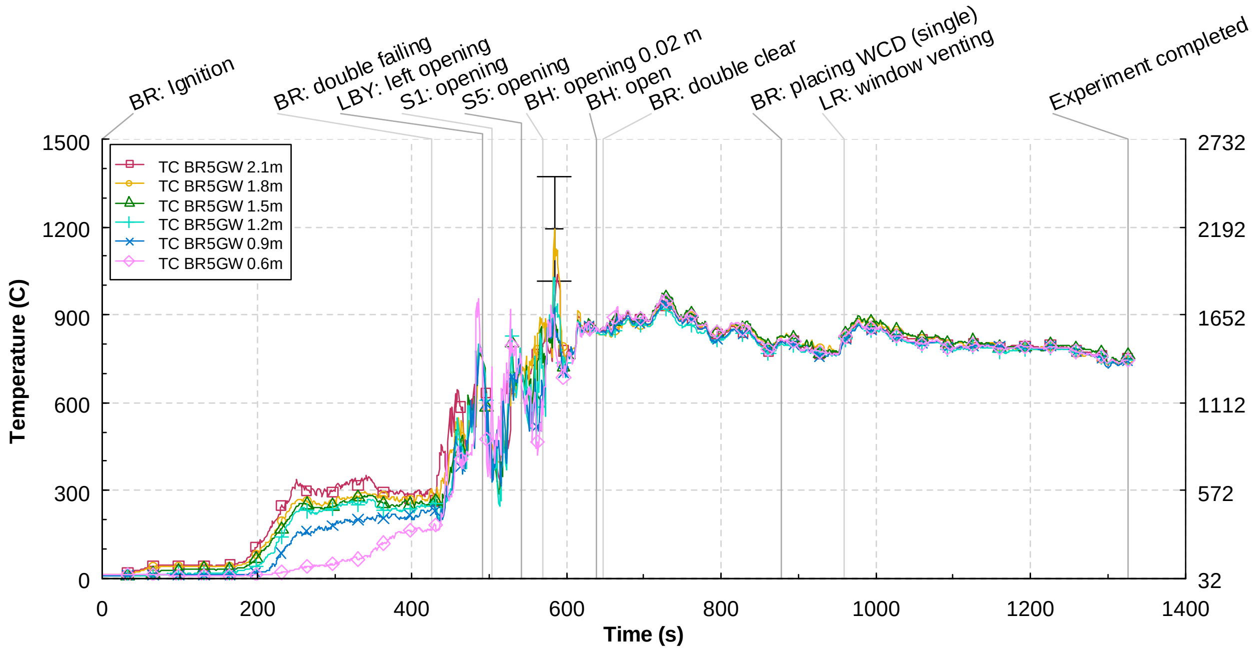



**Figure 9.4-97. Temperature versus time for the 5G bedroom thermocouple tree, Experiment 5G**

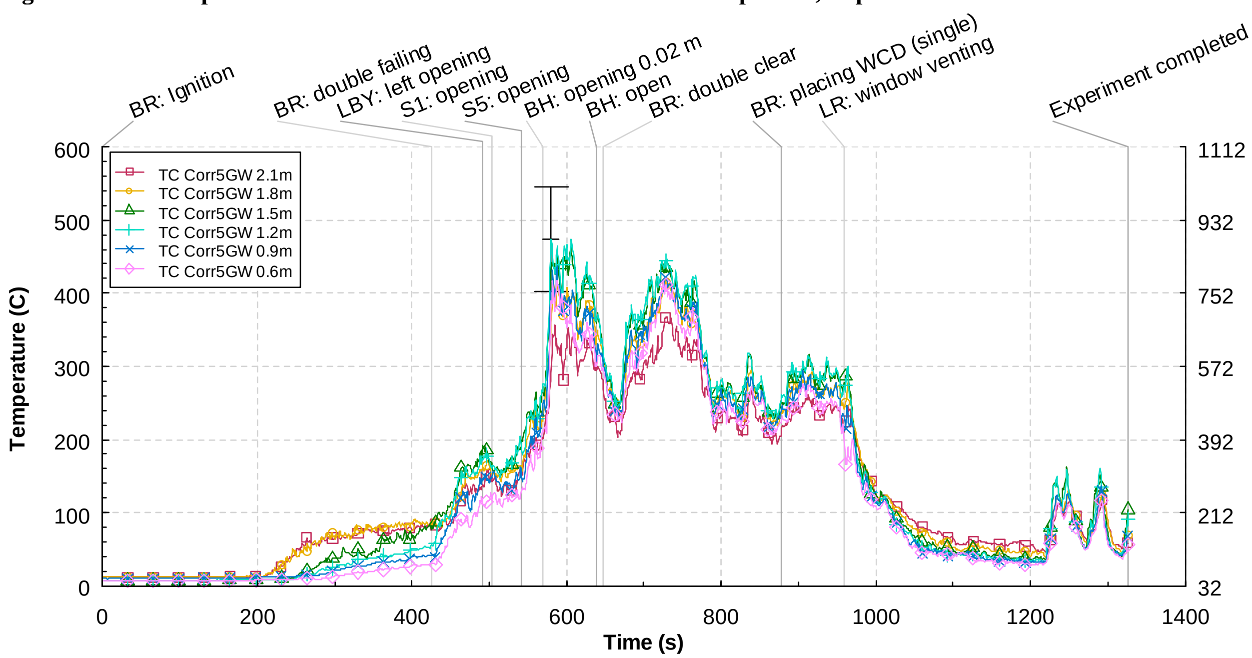



**Figure 9.4-98. Temperature versus time for the 5G hall thermocouple tree, Experiment 5G**

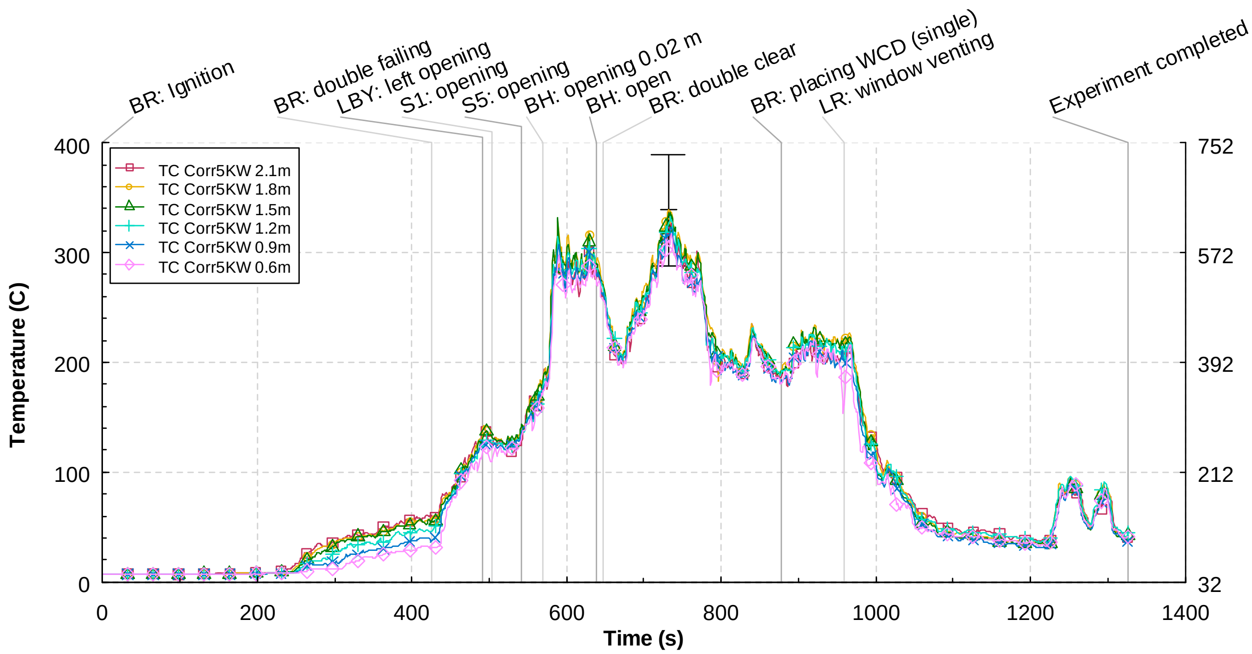



**Figure 9.4-99. Temperature versus time for the 5K hall thermocouple tree, Experiment 5G**

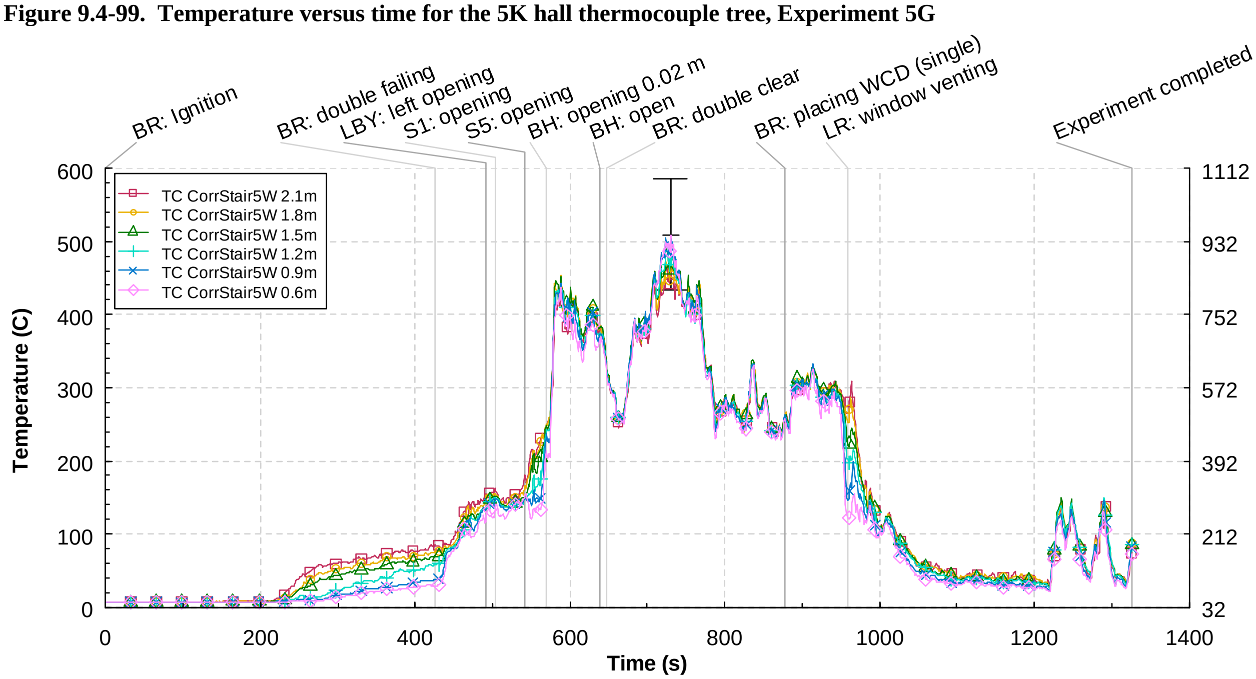



**Figure 9.4-100. Temperature versus time for the 5th floor stair hall thermocouple tree, Experiment 5G**

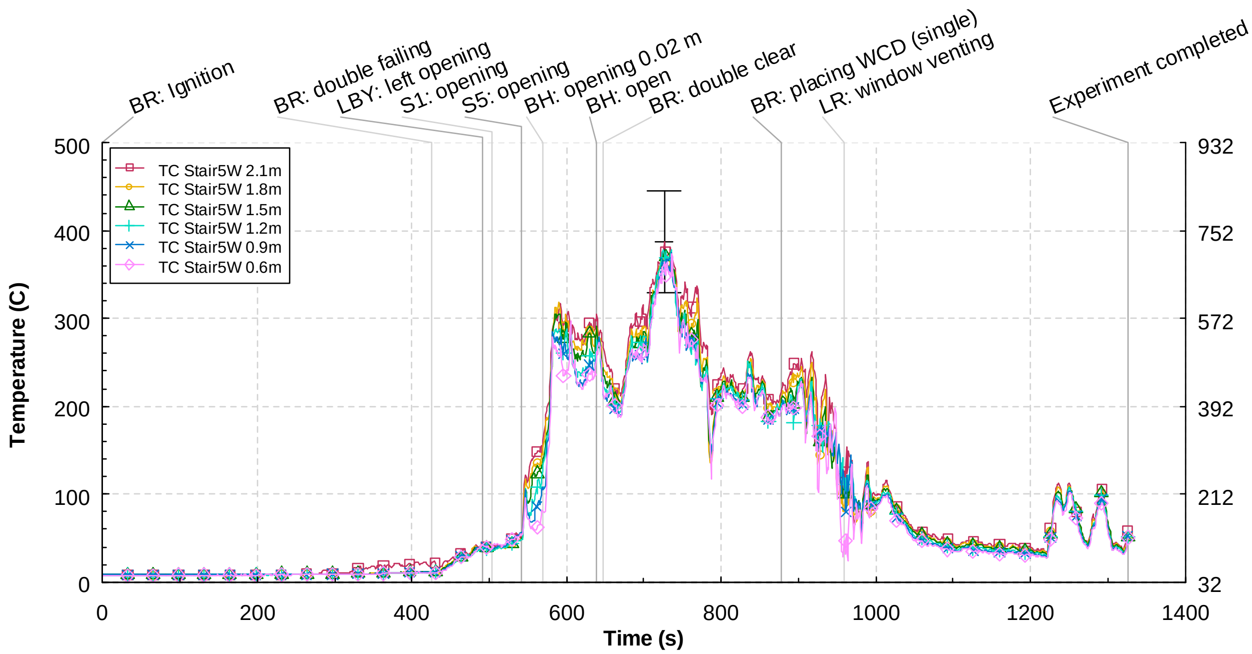



**Figure 9.4-101. Temperature versus time for the 5th floor stairwell thermocouple tree, Experiment 5G**

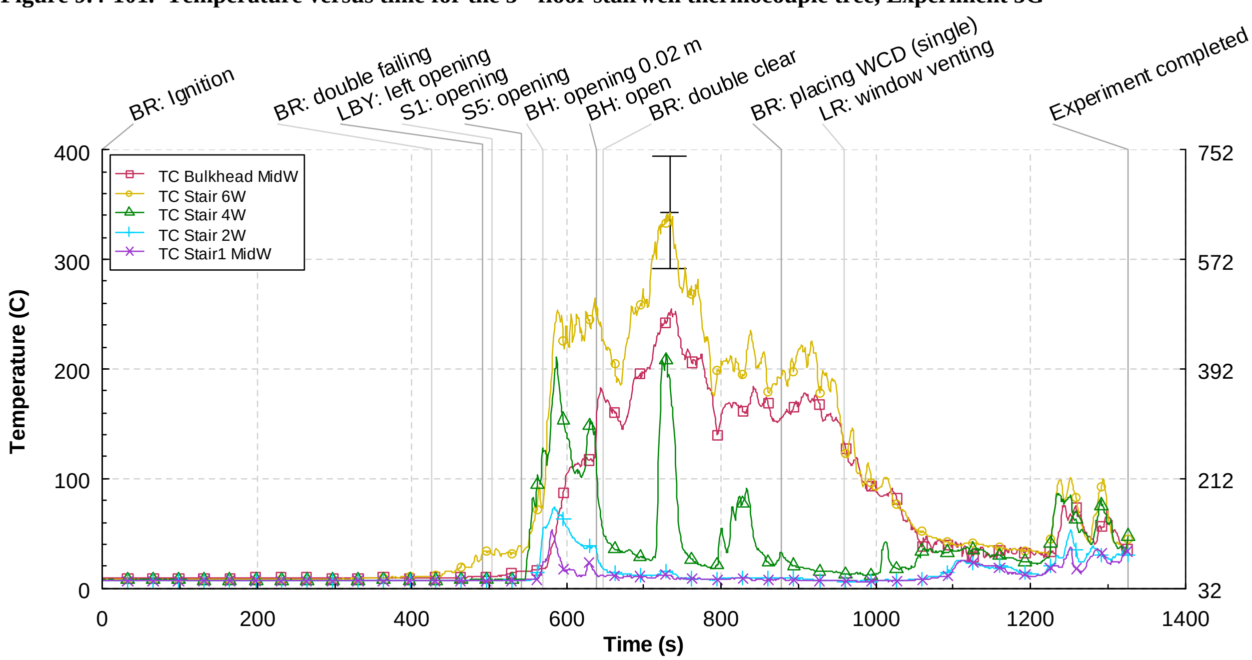



**Figure 9.4-102. Temperature versus time for the stair thermocouples, Experiment 5G**

### 9.4.10.2 Pressures

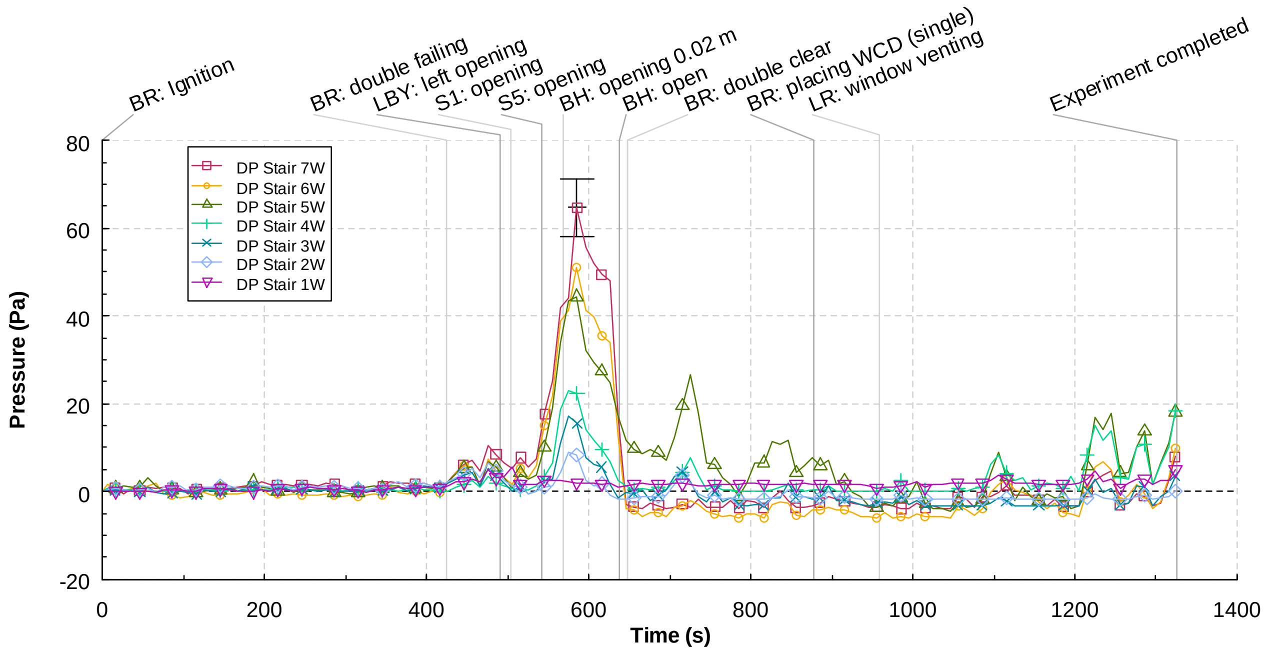



**Figure 9.4-103. Differential pressure versus time for the stairwell bi-directional probes, Experiment 5G**

### 9.4.10.3 Velocities

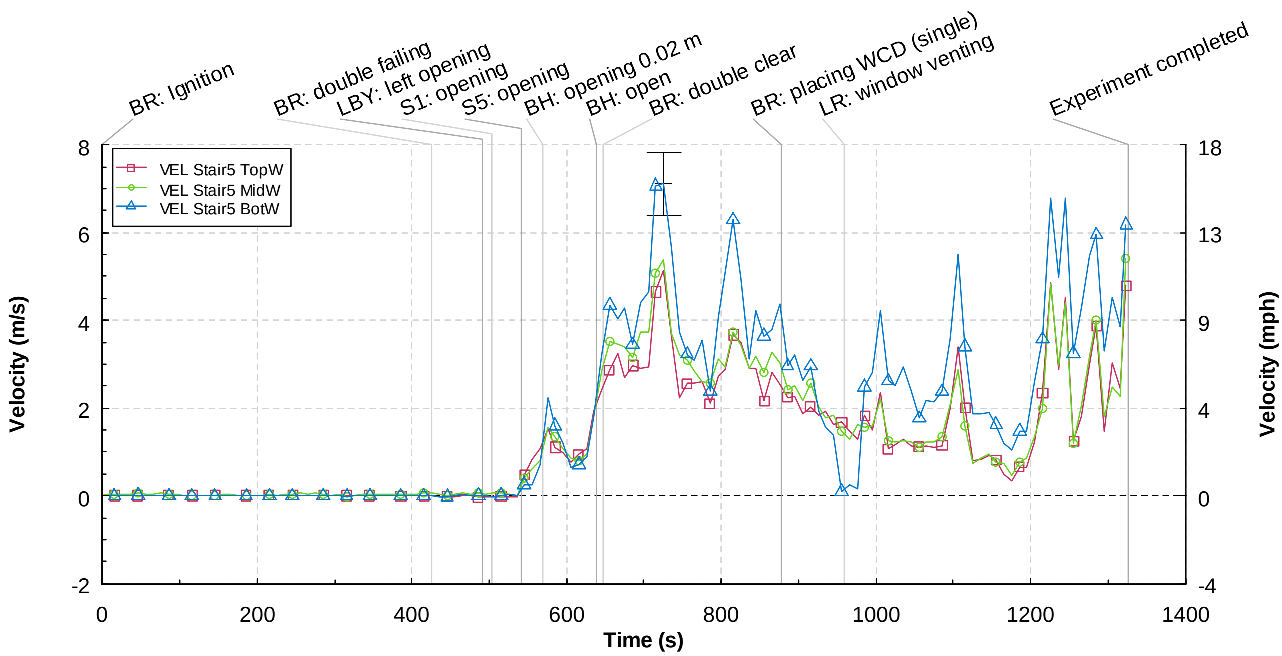



**Figure 9.4-104. Velocity versus time for the 5th floor stairwell bi-directional probes, Experiment 5G**

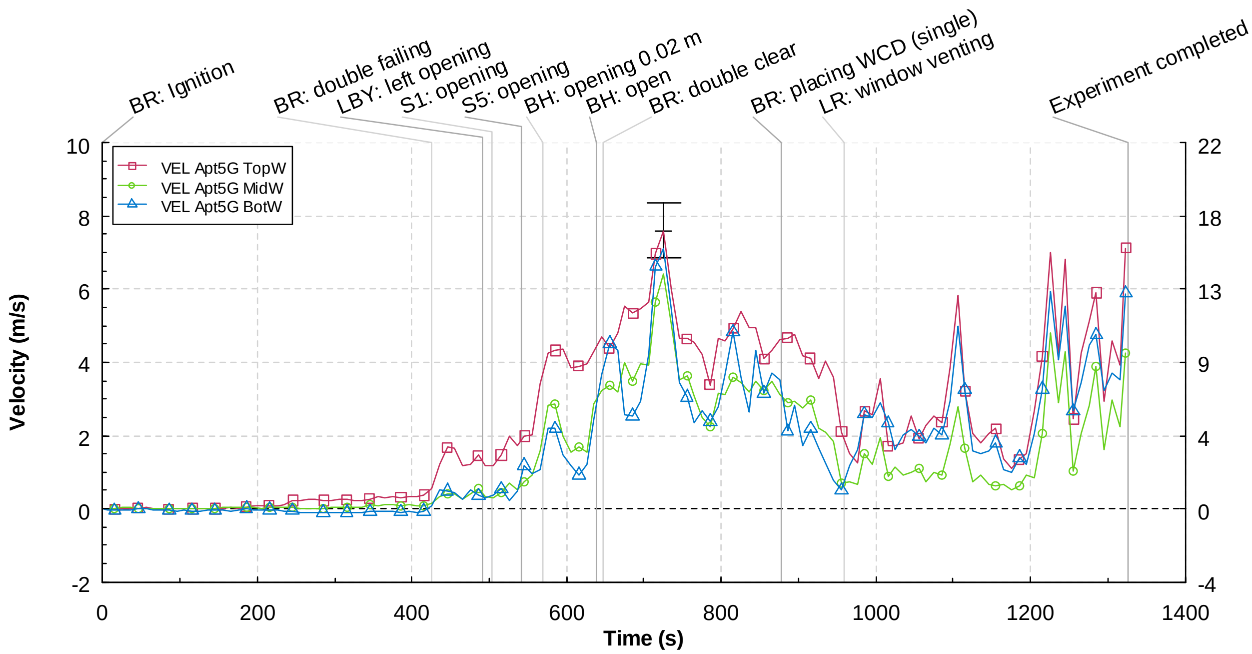



**Figure 9.4-105. Velocity versus time for the apartment 5G doorway bi-directional probes, Experiment 5G**

## 9.4.11 Experiment 5G2

### 9.4.11.1 Temperatures

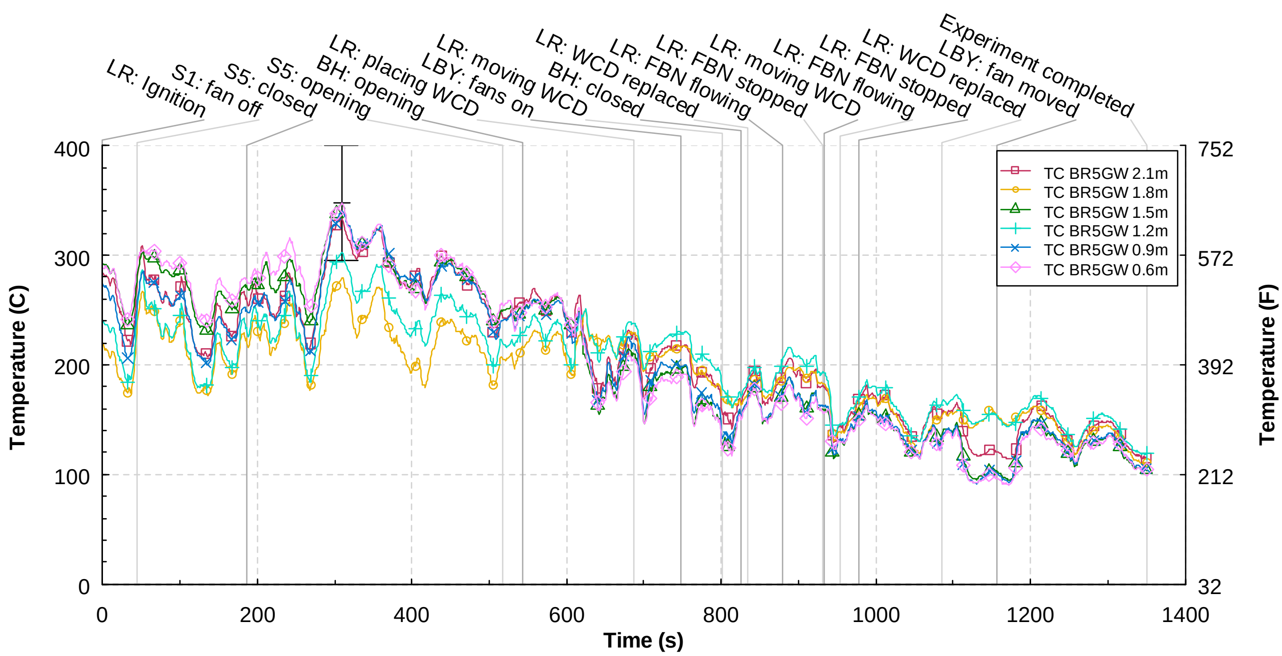



**Figure 9.4-106. Temperature versus time for the 5G2 bedroom thermocouple tree, Experiment 5G2**

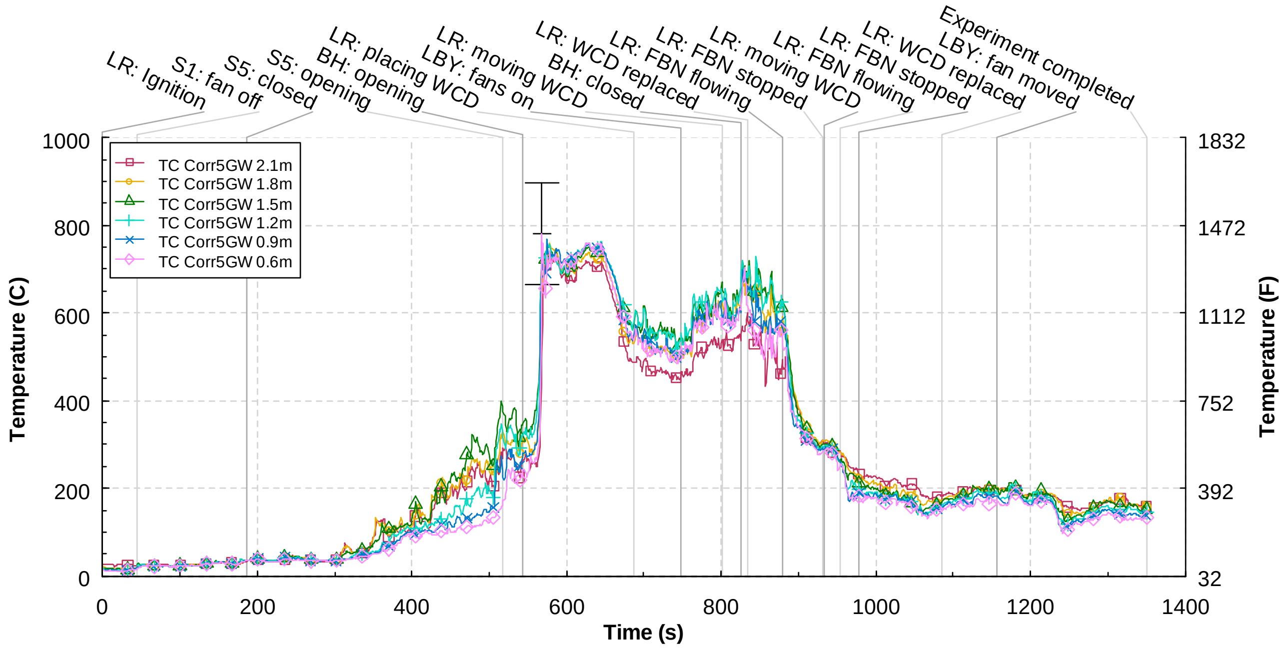



**Figure 9.4-107. Temperature versus time for the 5G2 hall thermocouple tree, Experiment 5G2**

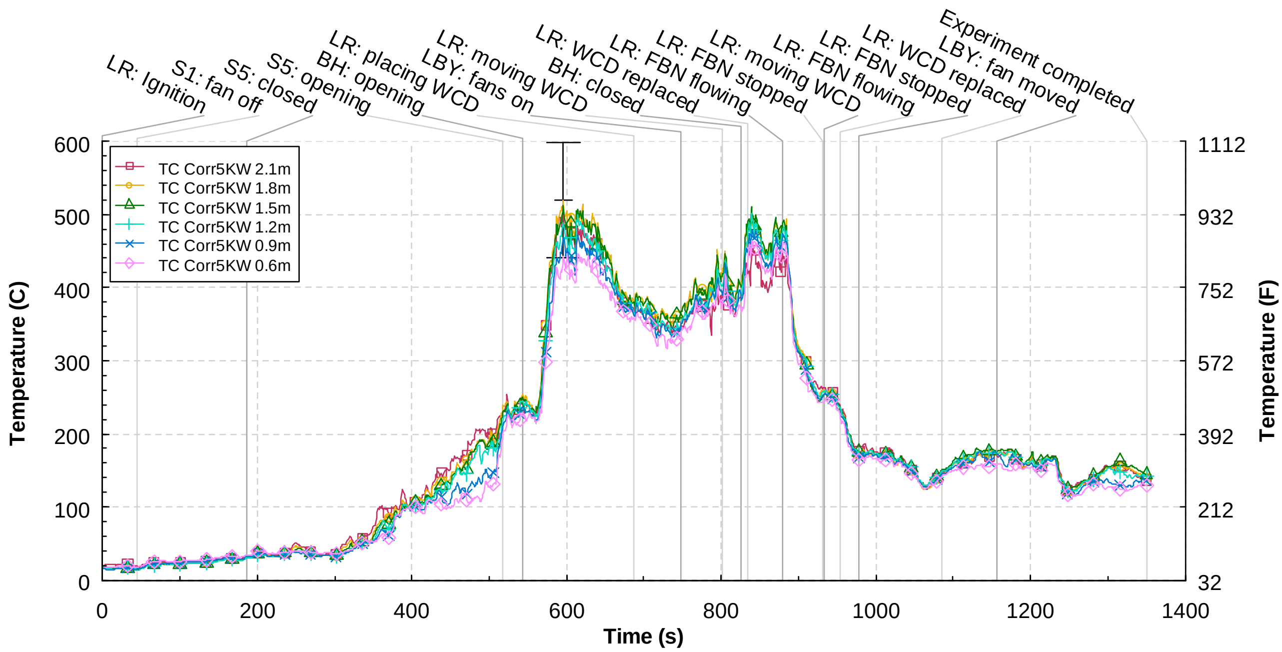



**Figure 9.4-108. Temperature versus time for the 5K hall thermocouple tree, Experiment 5G2**

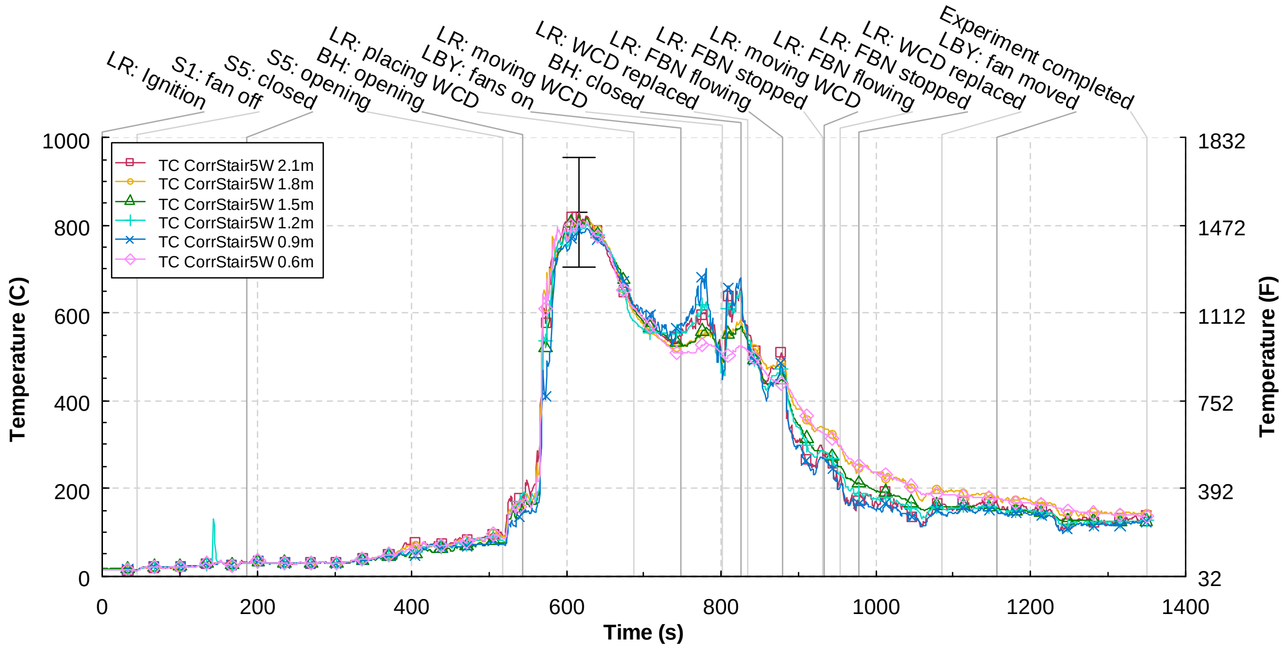



**Figure 9.4-109. Temperature versus time for the 5th floor stair hall thermocouple tree, Experiment 5G2**

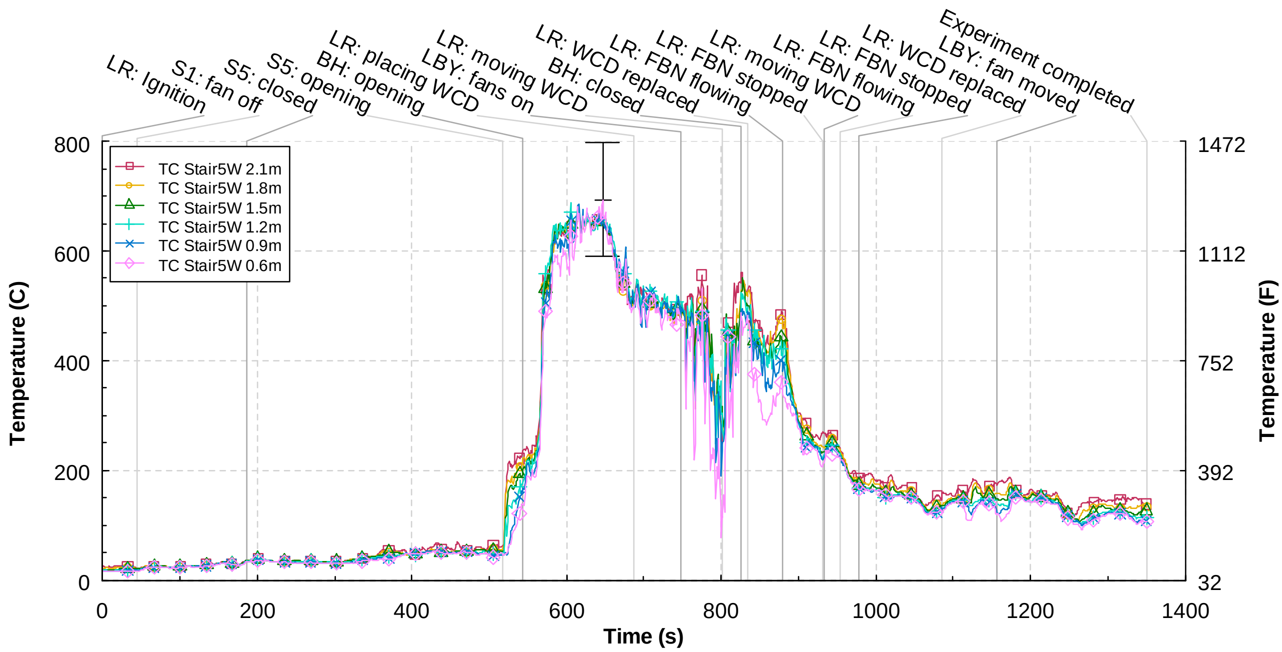



**Figure 9.4-110. Temperature versus time for the 5th floor stairwell thermocouple tree, Experiment 5G2**

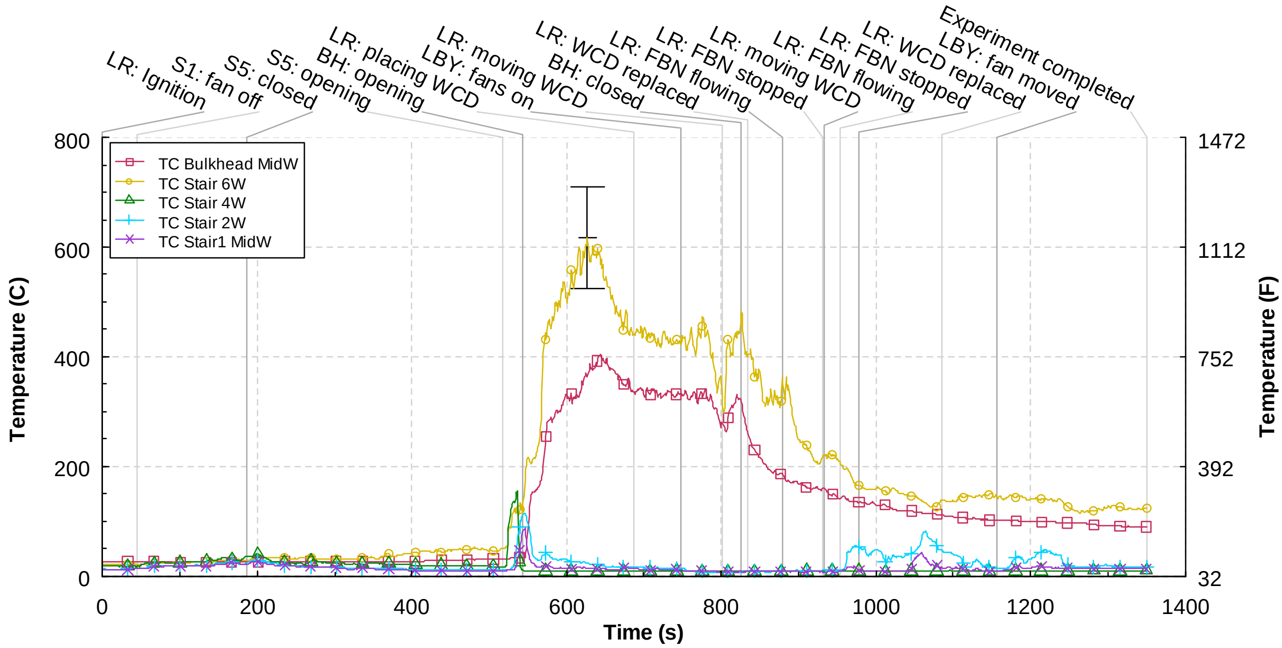



**Figure 9.4-111. Temperature versus time for the stair thermocouples, Experiment 5G2**

## 9.4.11.2 Pressures

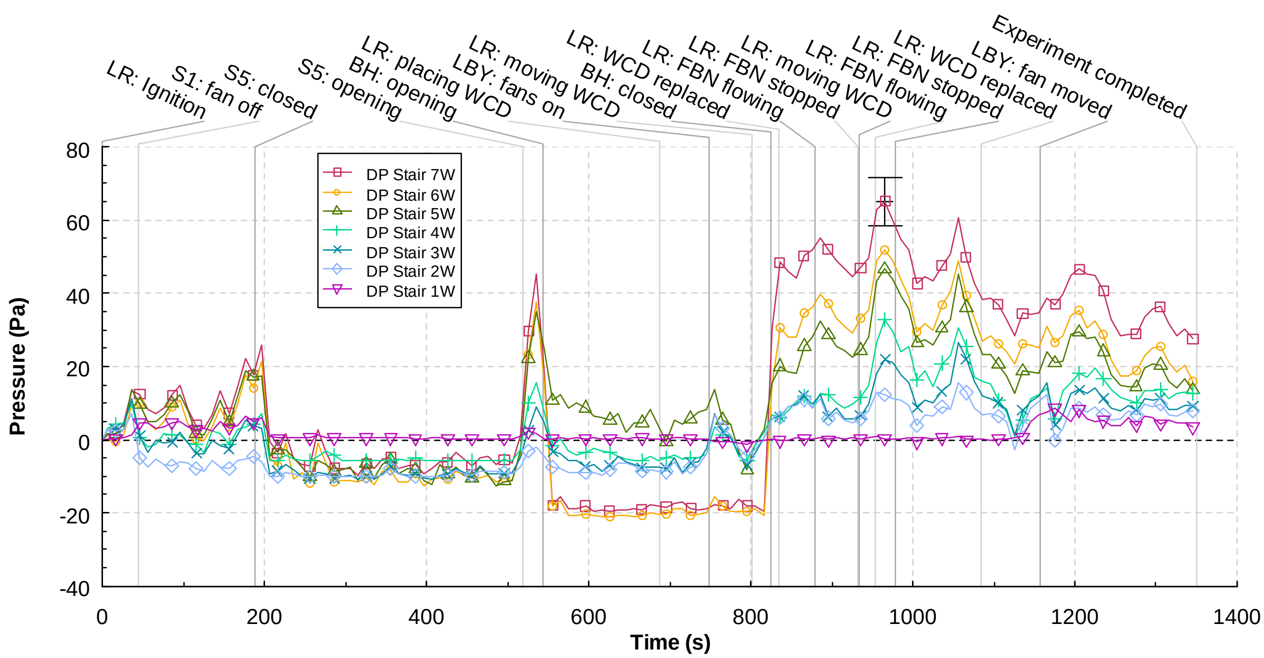



**Figure 9.4-112. Differential pressure versus time for the stairwell bi-directional probes, Experiment 5G2**

### 9.4.11.3 Velocities

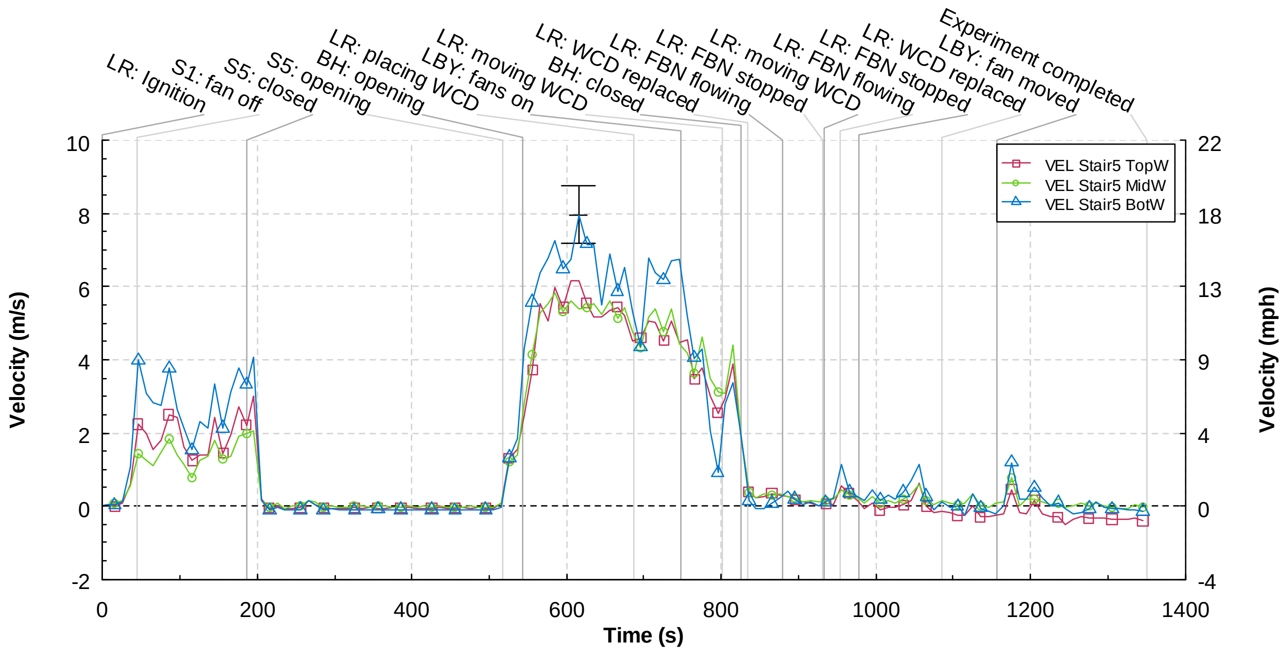



**Figure 9.4-113. Velocity versus time for the 5th floor stairwell bi-directional probes, Experiment 5G2**

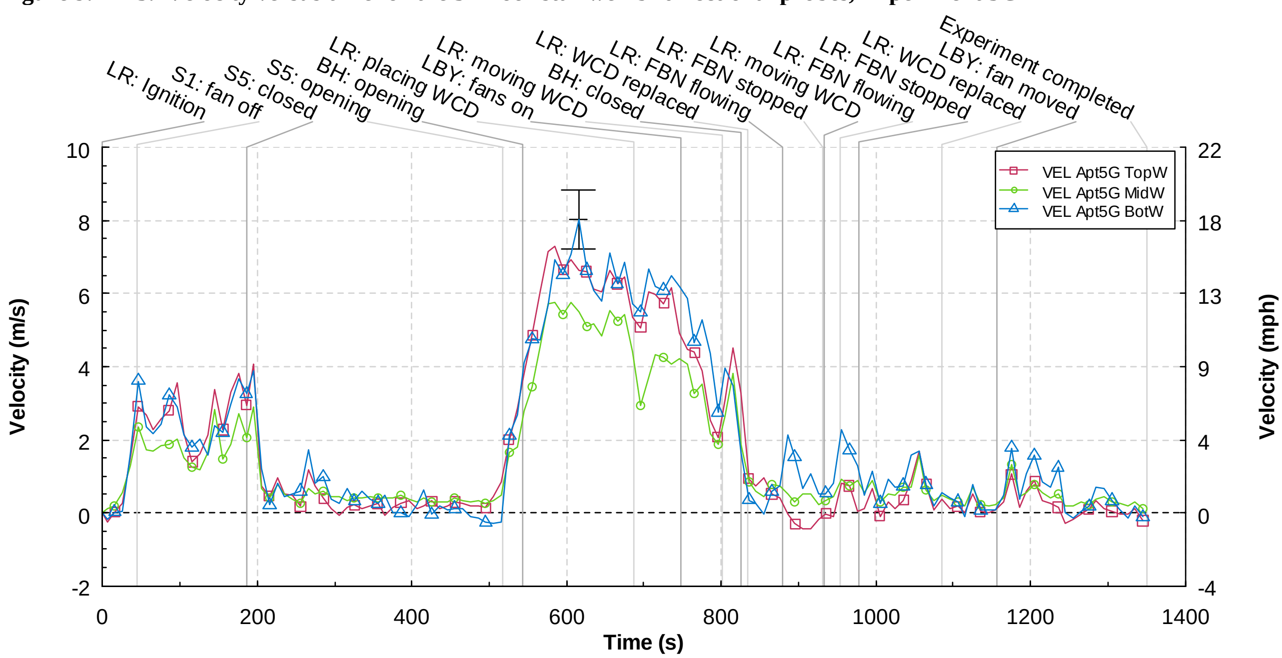



**Figure 9.4-114. Velocity versus time for the apartment 5G doorway bi-directional probes, Experiment 5G2**

### 9.4.12 Experiment 3E

#### 9.4.12.1 Temperatures

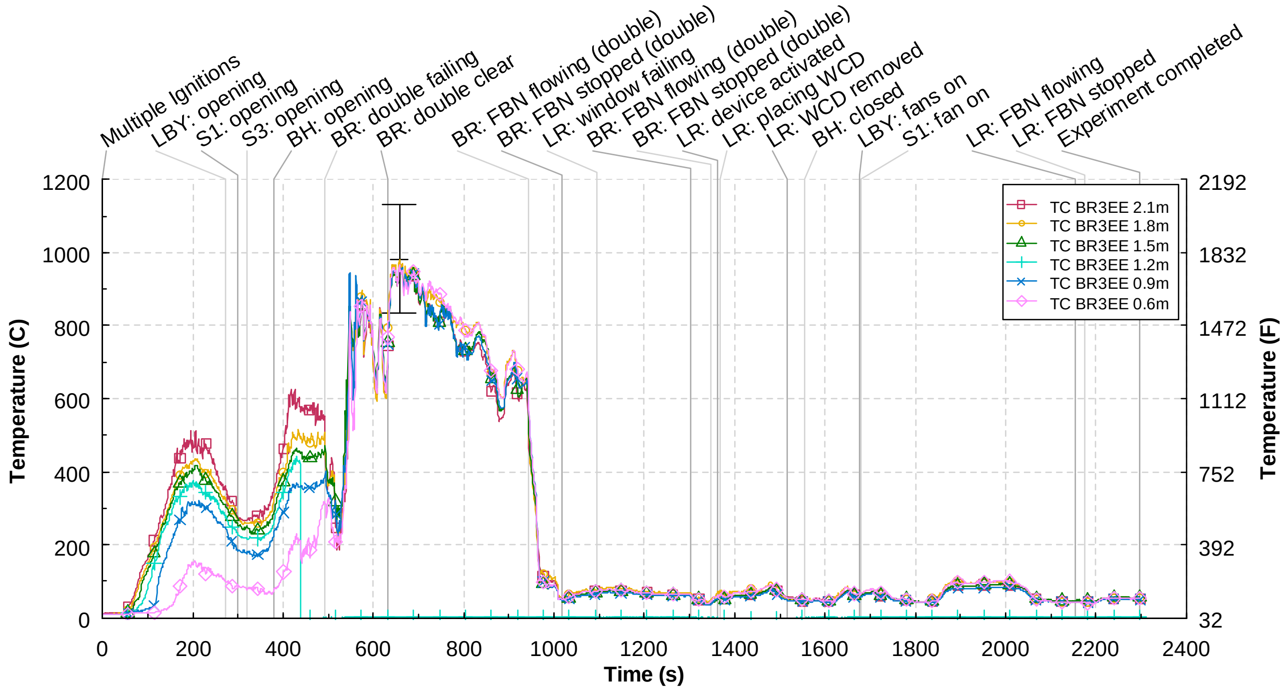



**Figure 9.4-115. Temperature versus time for the 3E bedroom thermocouple tree, Experiment 3E**

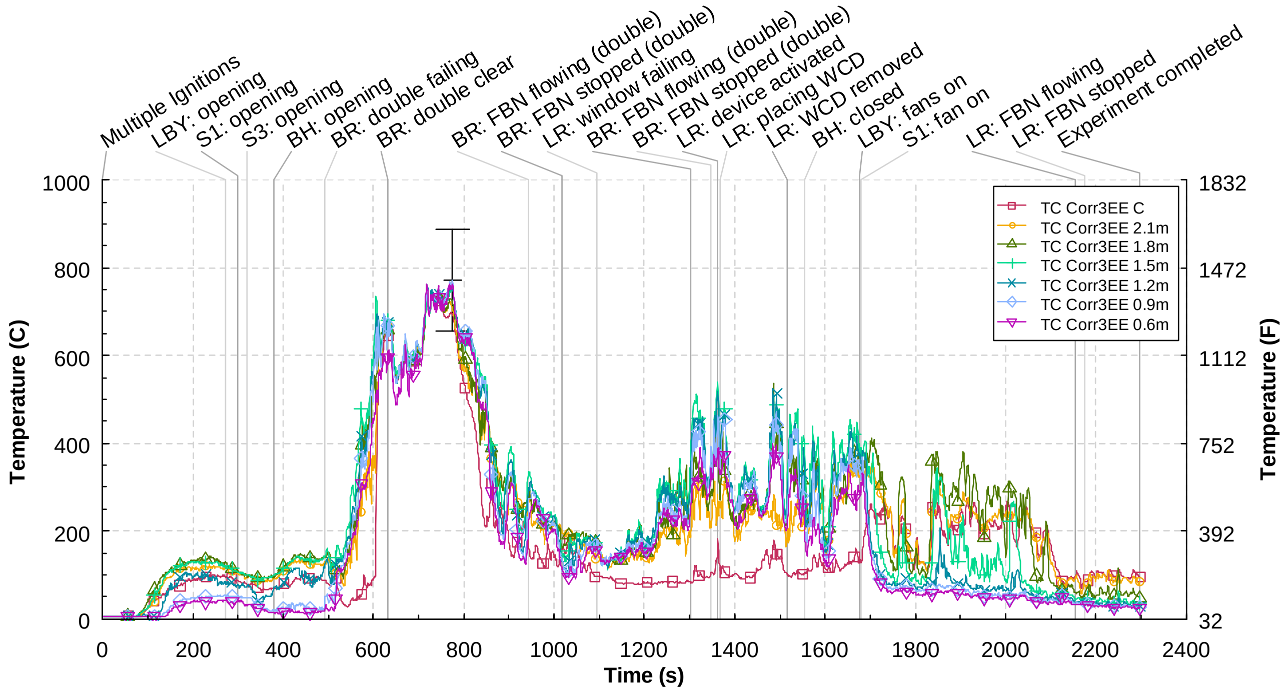



**Figure 9.4-116. Temperature versus time for the 3E hall thermocouple tree, Experiment 3E**

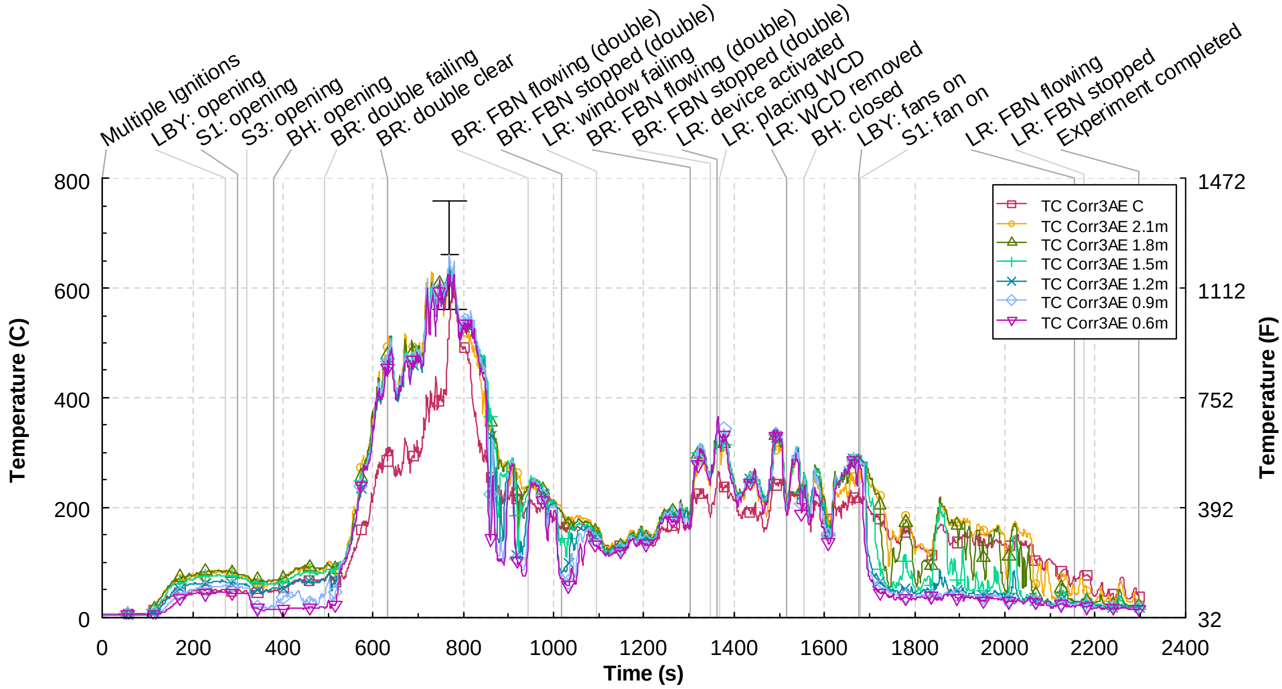



**Figure 9.4-117. Temperature versus time for the 3A hall thermocouple tree, Experiment 3E**

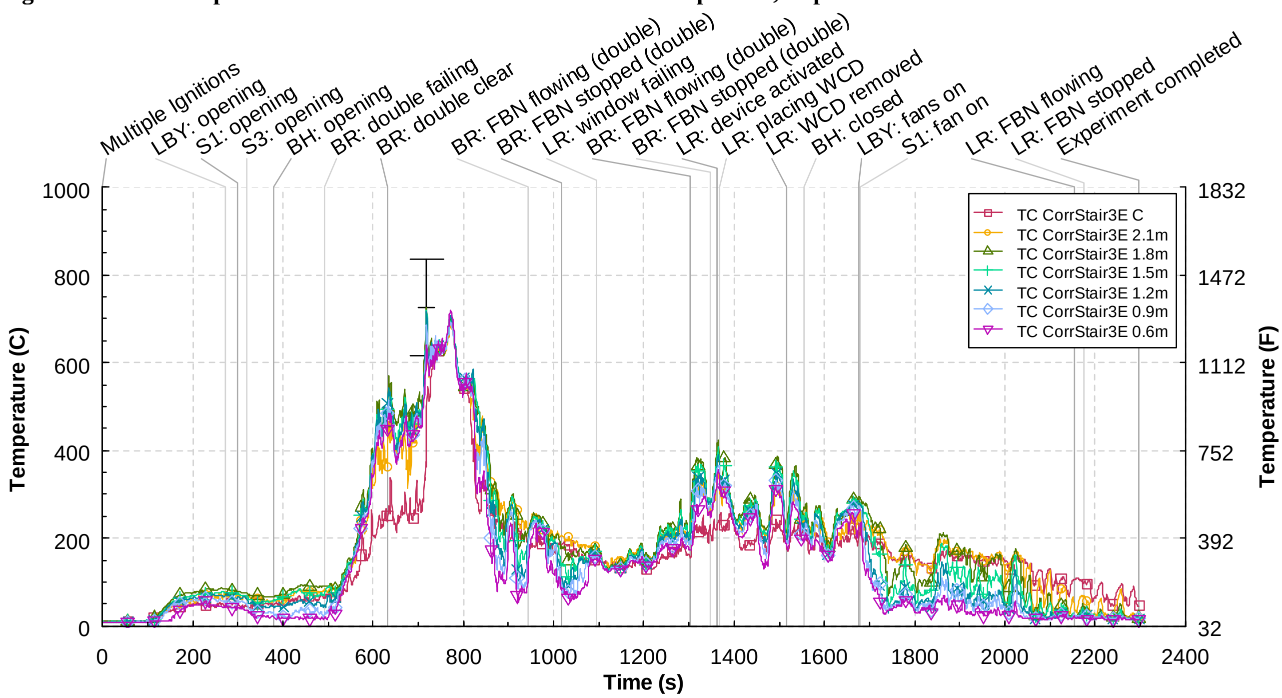



**Figure 9.4-118. Temperature versus time for the 3rd floor stair hall thermocouple tree, Experiment 3E**

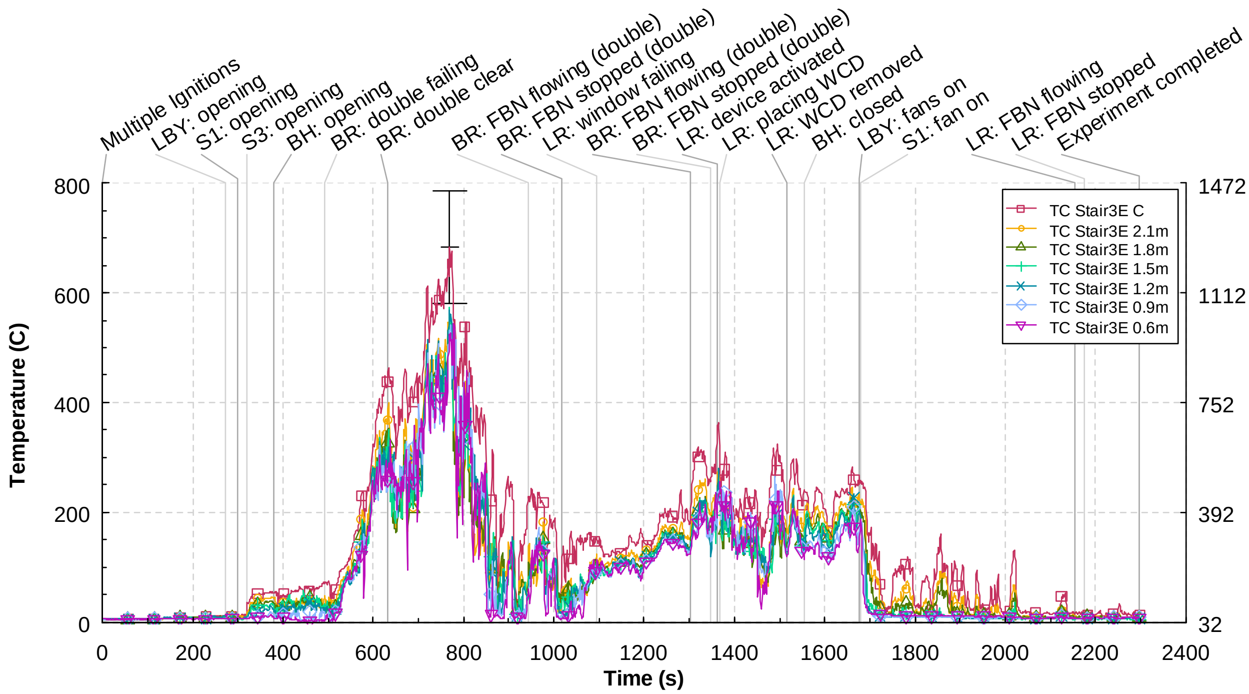



**Figure 9.4-119. Temperature versus time for the 3rd floor stairwell thermocouple tree, Experiment 3E**

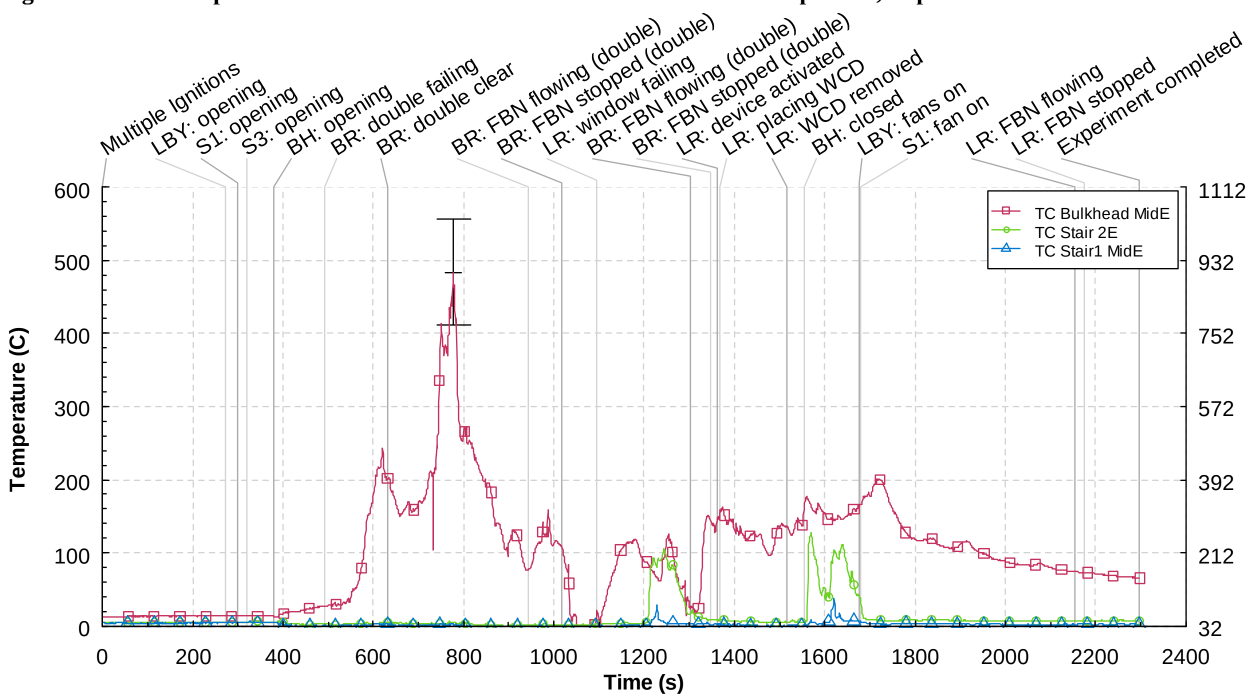



**Figure 9.4-120. Temperature versus time for the stair thermocouples, Experiment 3E**

### 9.4.12.2 Pressures

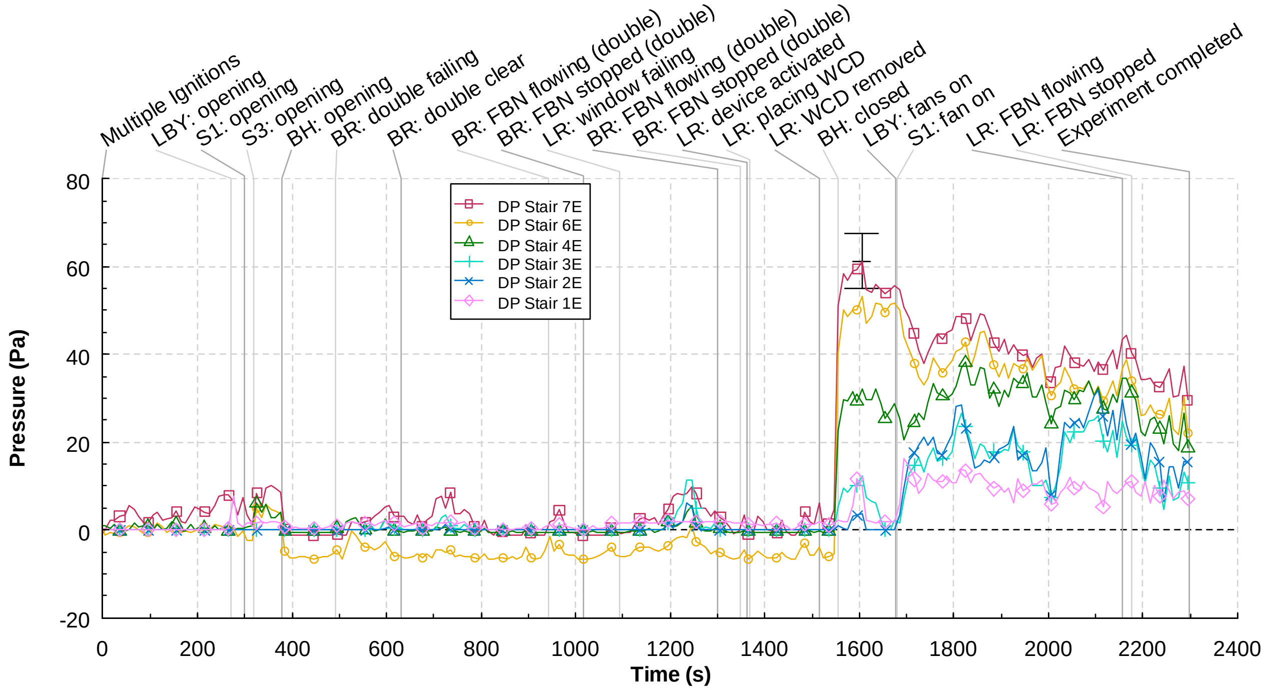



**Figure 9.4-121. Differential pressure versus time for the stairwell bi-directional probes, Experiment 3E**

### 9.4.12.3 Velocities

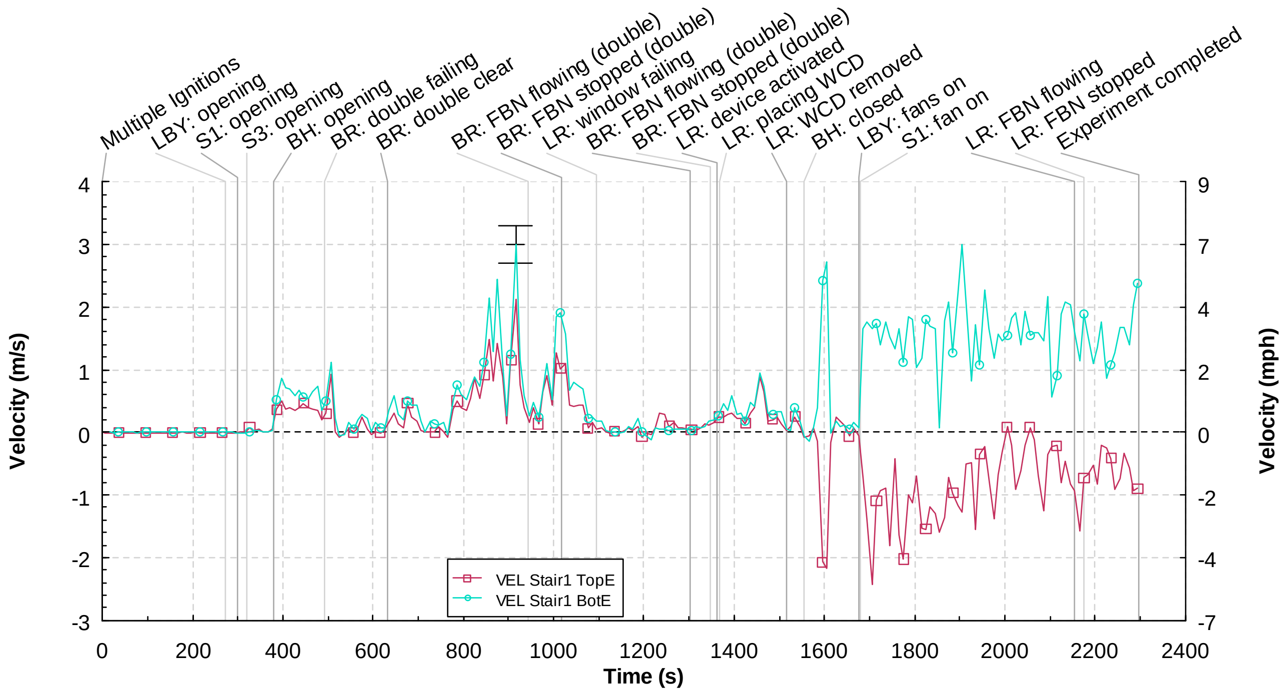



**Figure 9.4-122. Velocity versus time for the 1st floor stairwell bi-directional probes, Experiment 3E**

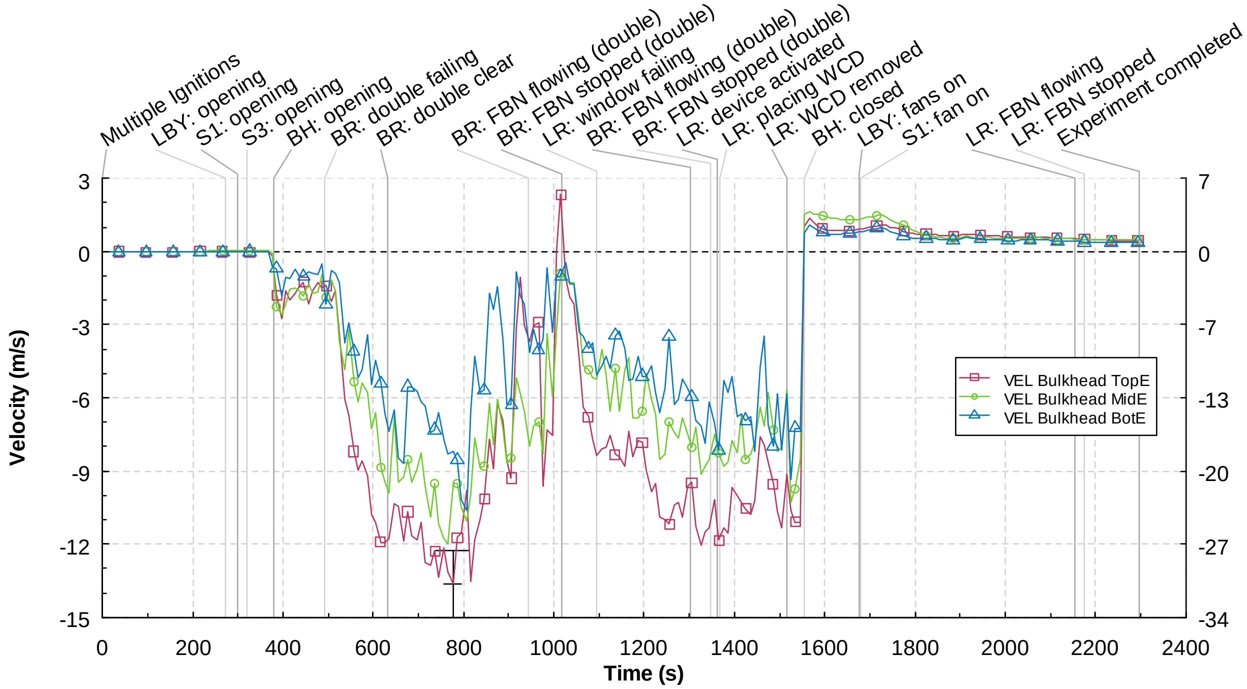



**Figure 9.4-123. Velocity versus time for the bulkhead bi-directional probes, Experiment 3E**

## 9.4.13 Experiment 3A

### 9.4.13.1 Temperatures

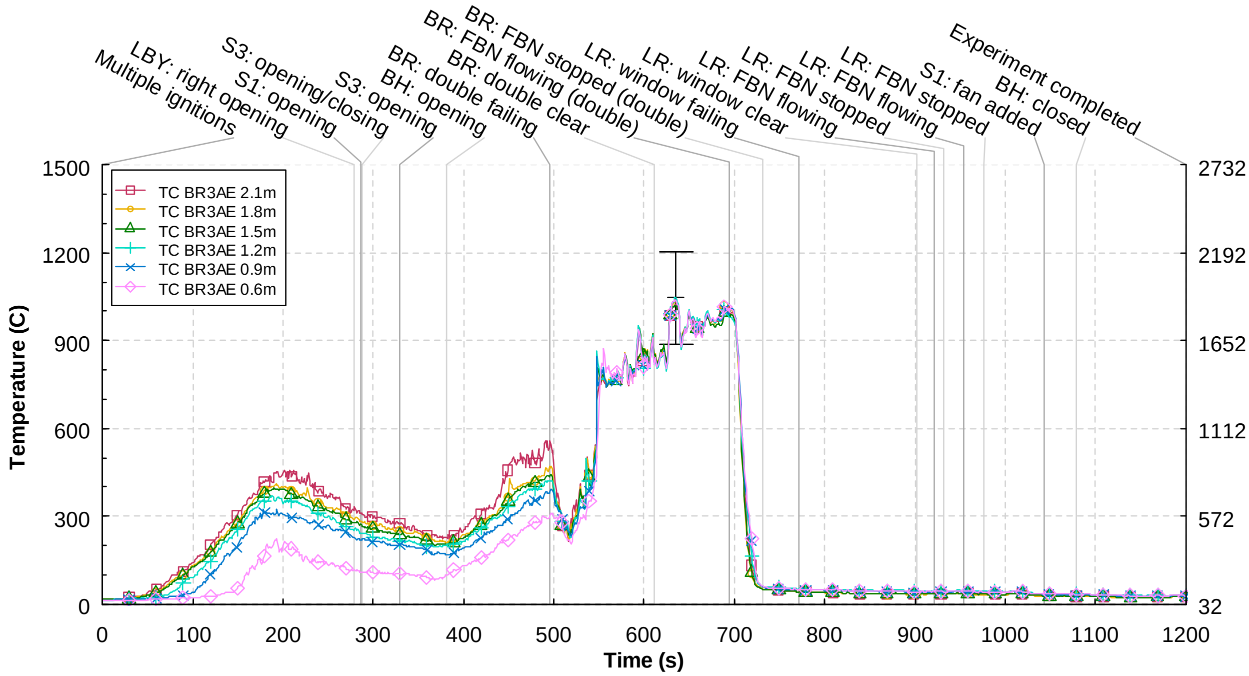



**Figure 9.4-124. Temperature versus time for the 3A bedroom thermocouple tree, Experiment 3A**

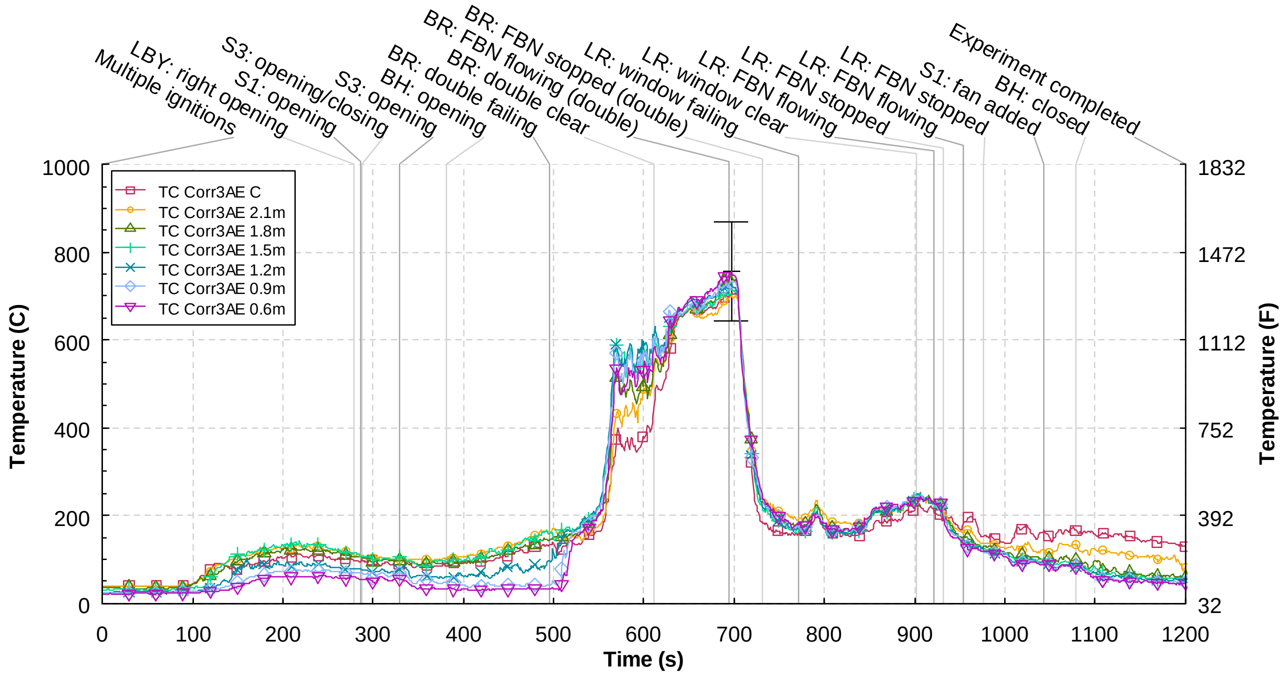



**Figure 9.4-125. Temperature versus time for the 3A hall thermocouple tree, Experiment 3A**

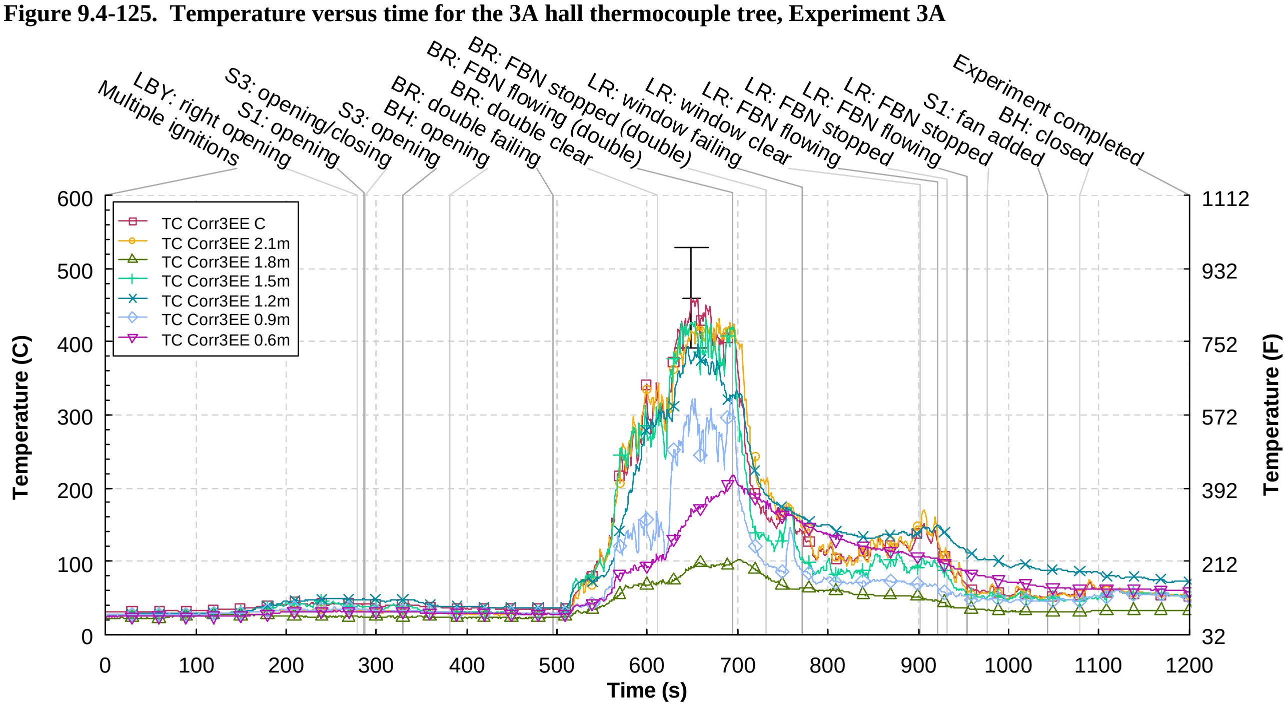



**Figure 9.4-126. Temperature versus time for the 3E hall thermocouple tree, Experiment 3A**

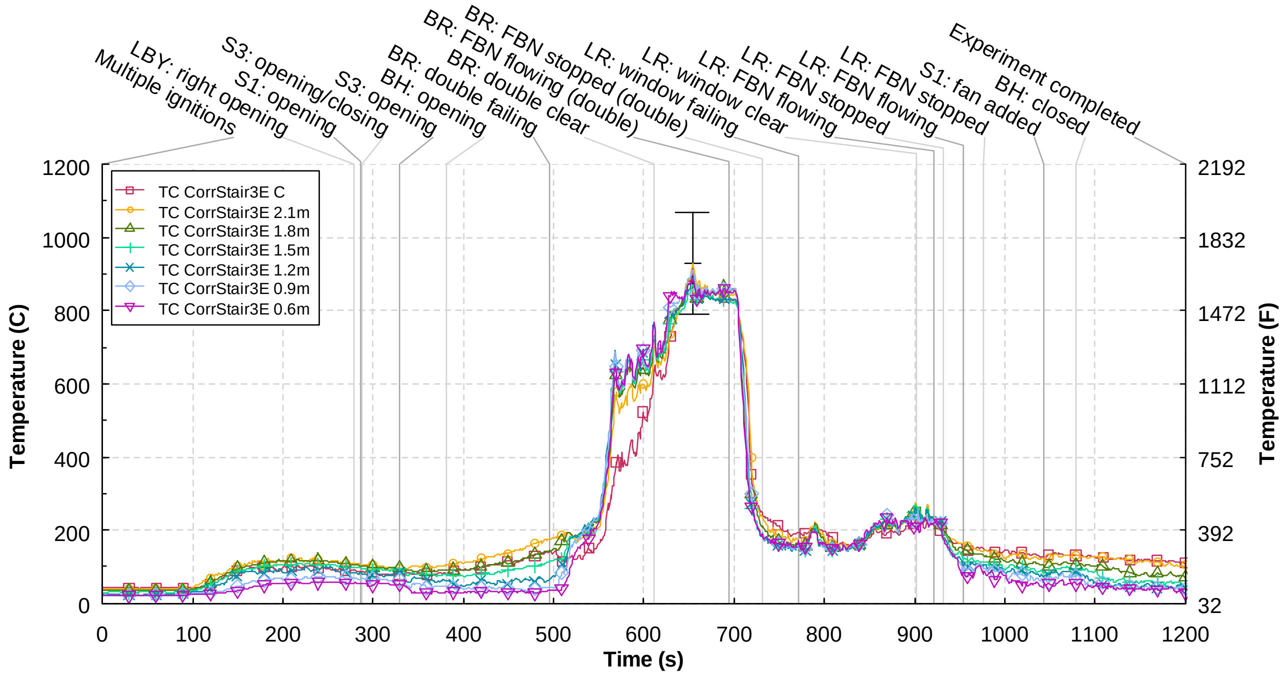



**Figure 9.4-127. Temperature versus time for the 3rd floor stair hall thermocouple tree, Experiment 3A**

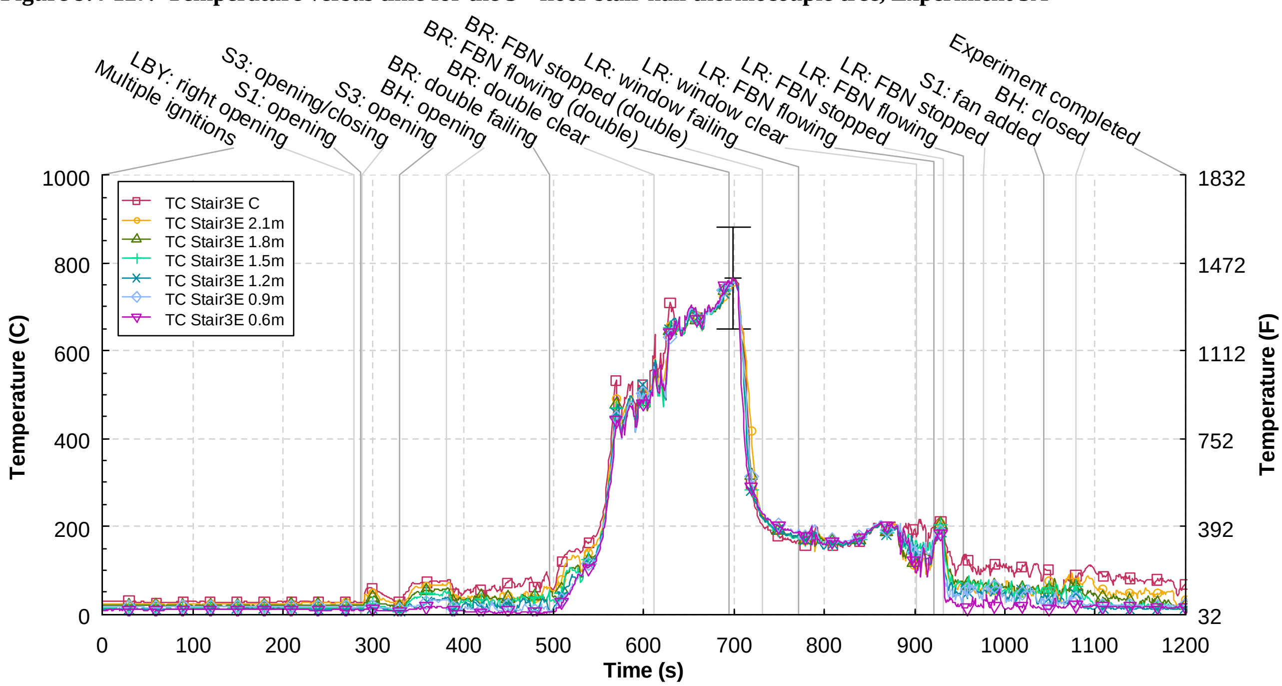



**Figure 9.4-128. Temperature versus time for the 3rd floor stairwell thermocouple tree, Experiment 3A**

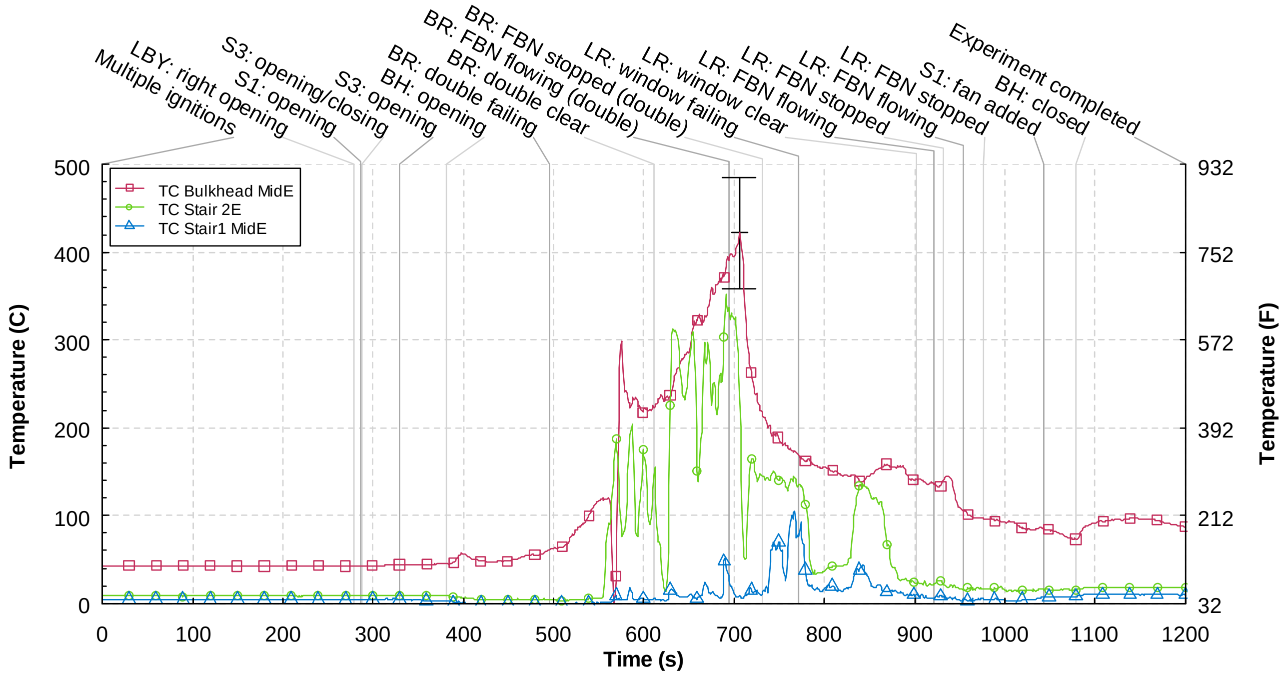



**Figure 9.4-129. Temperature versus time for the stair thermocouples, Experiment 3A**

## 9.4.13.2 Pressures

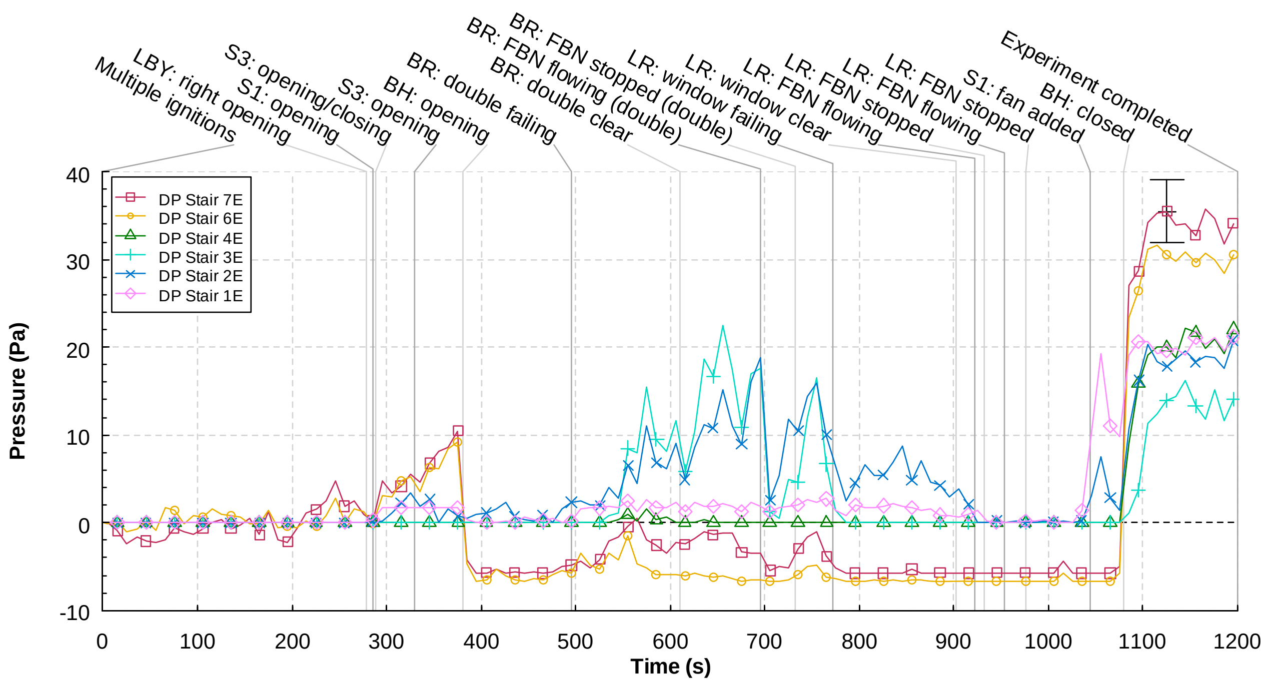



**Figure 9.4-130. Differential pressure versus time for the stairwell bi-directional probes, Experiment 3A**

### 9.4.13.3 Velocities

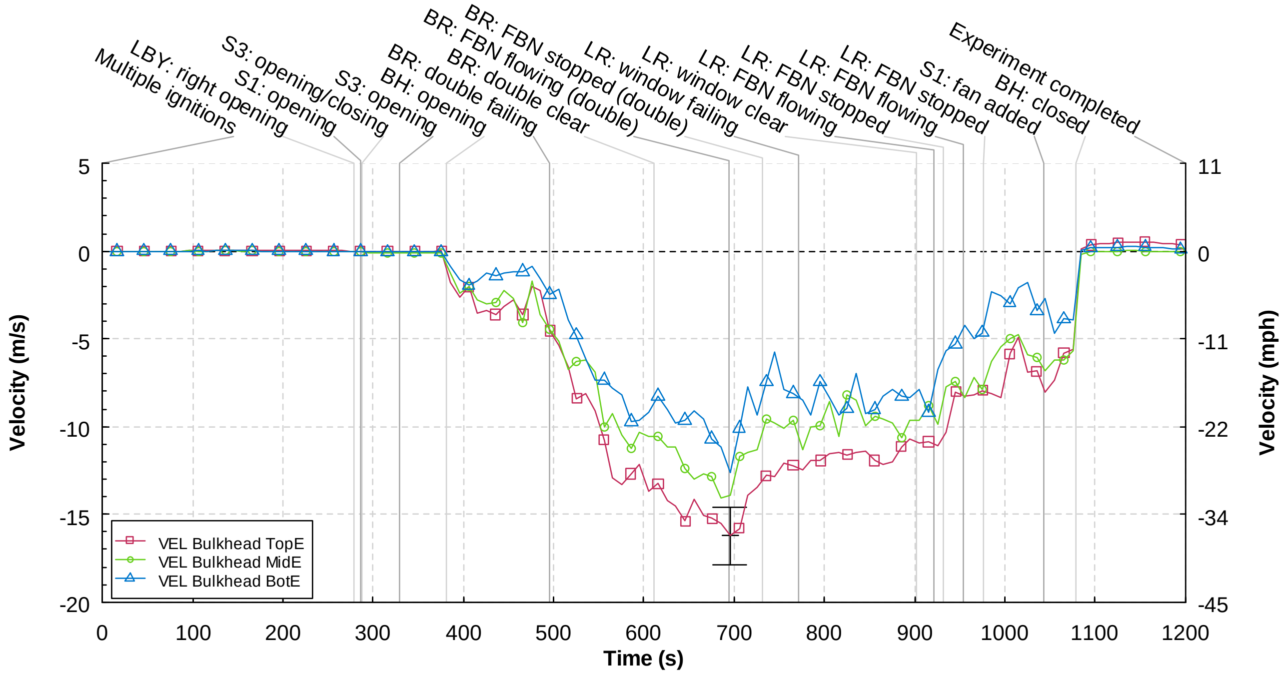



**Figure 9.4-131. Velocity versus time for the bulkhead bi-directional probes, Experiment 3A**

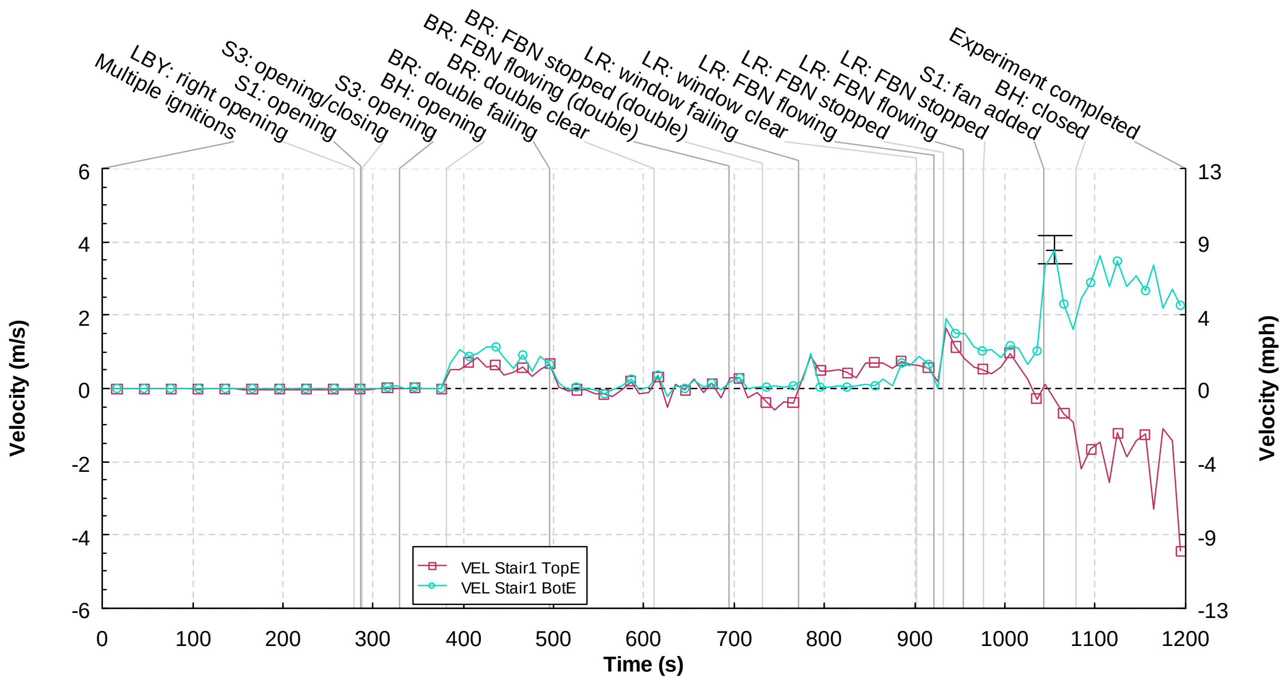



**Figure 9.4-132. Velocity versus time for the 1st floor stairwell bi-directional probes, Experiment 3A**

## 9.4.14 Experiment 3G/K

### 9.4.14.1 Temperatures

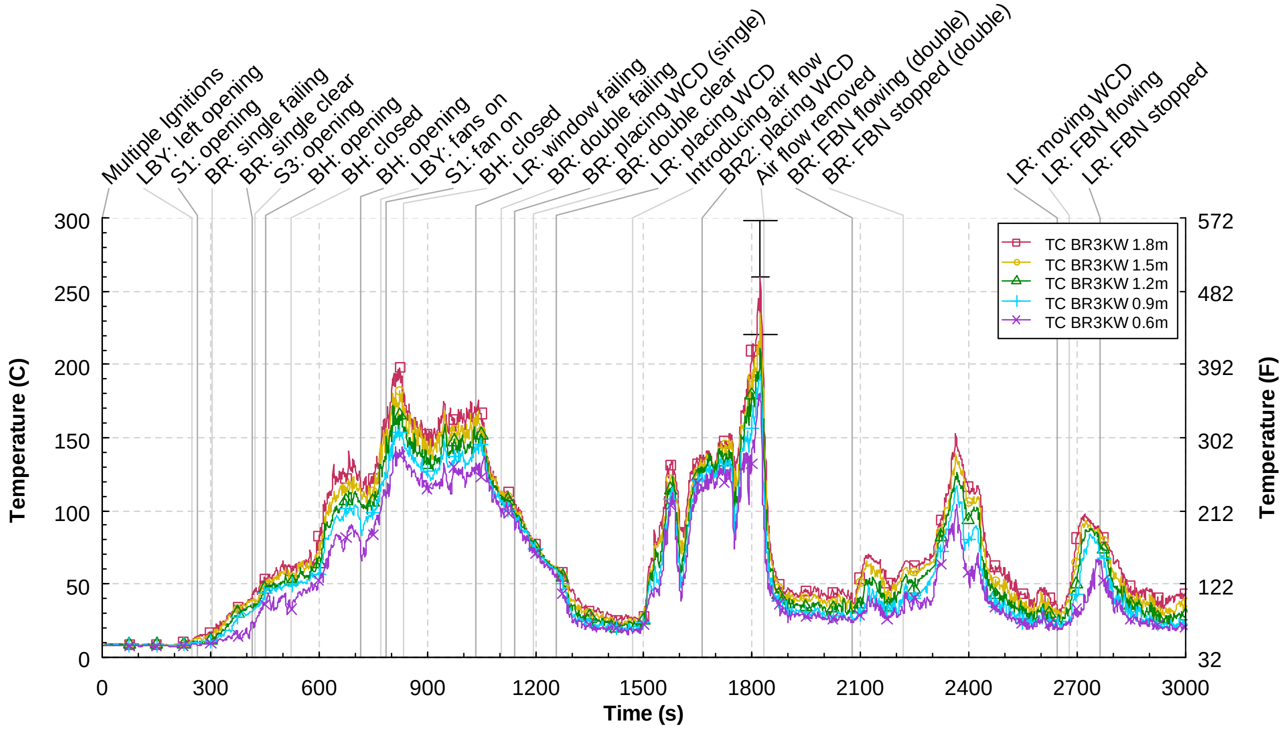



**Figure 9.4-133. Temperature versus time for the 3G_K bedroom thermocouple tree, Experiment 3G_K**

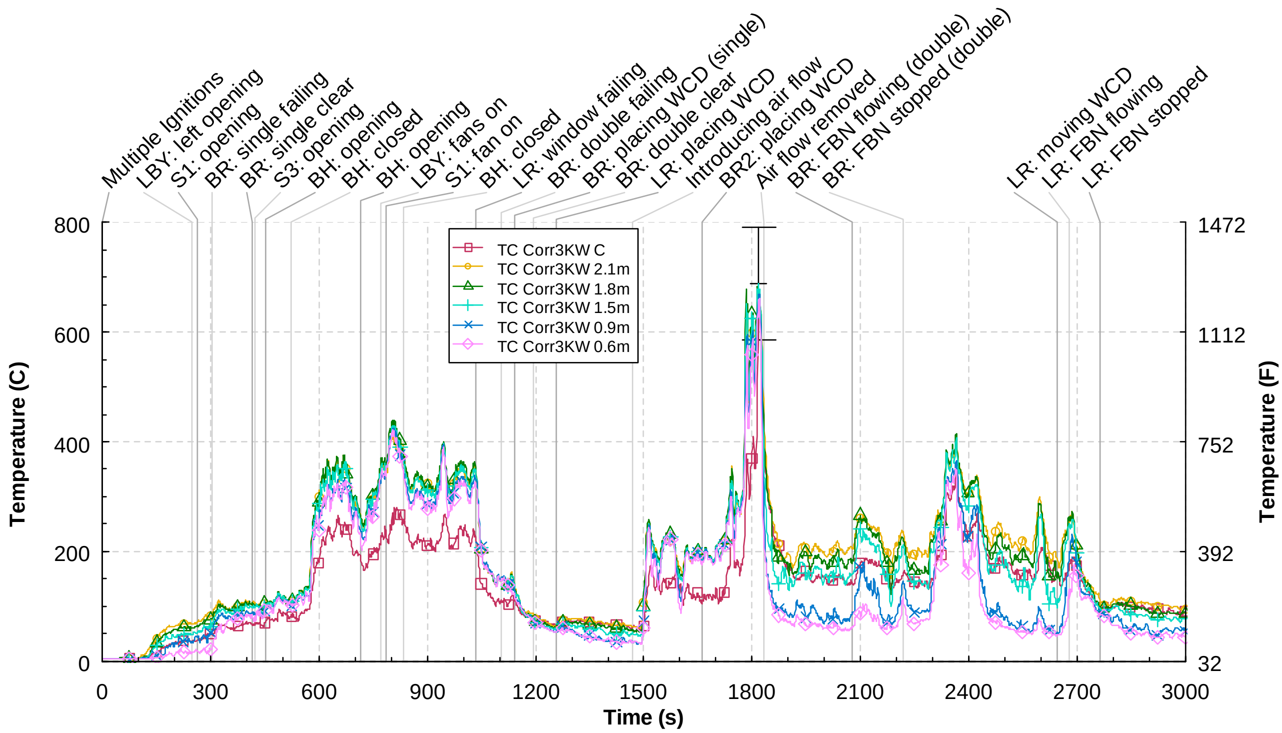



**Figure 9.4-134. Temperature versus time for the 3G_K hall thermocouple tree, Experiment 3G_K**

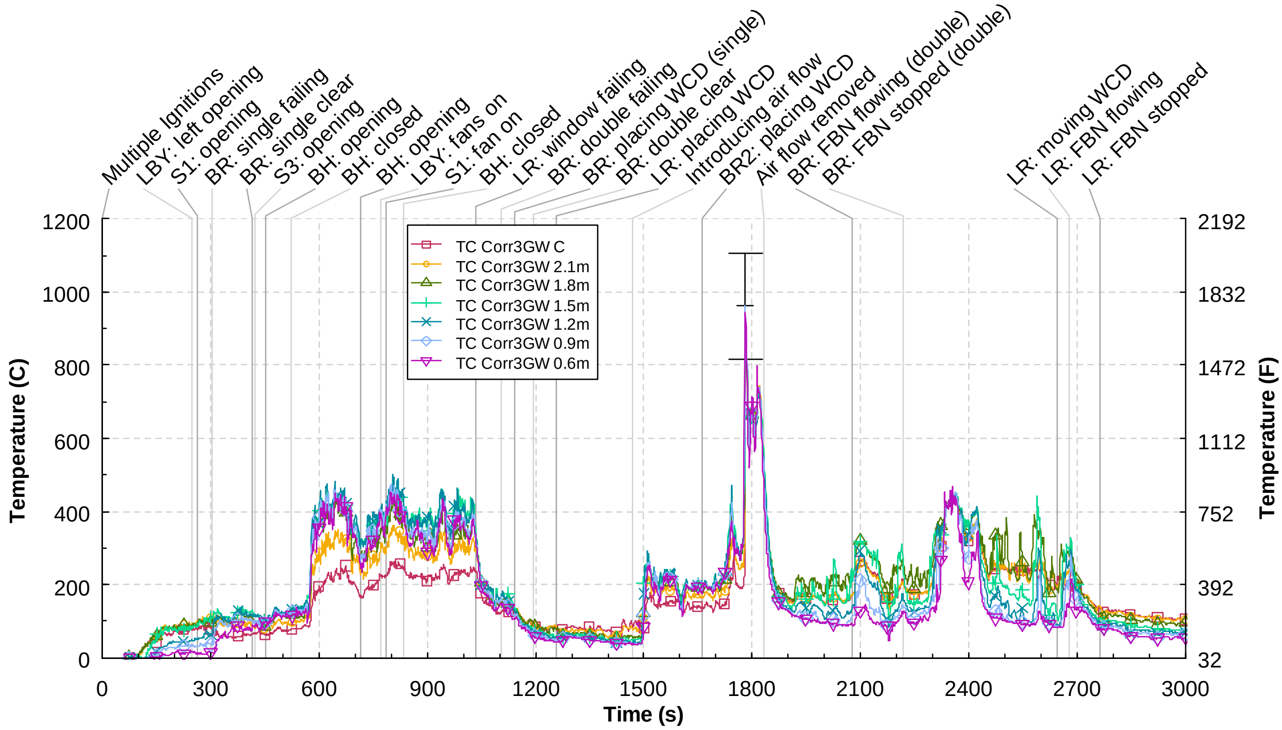



**Figure 9.4-135. Temperature versus time for the 7K hall thermocouple tree, Experiment 3G_K**

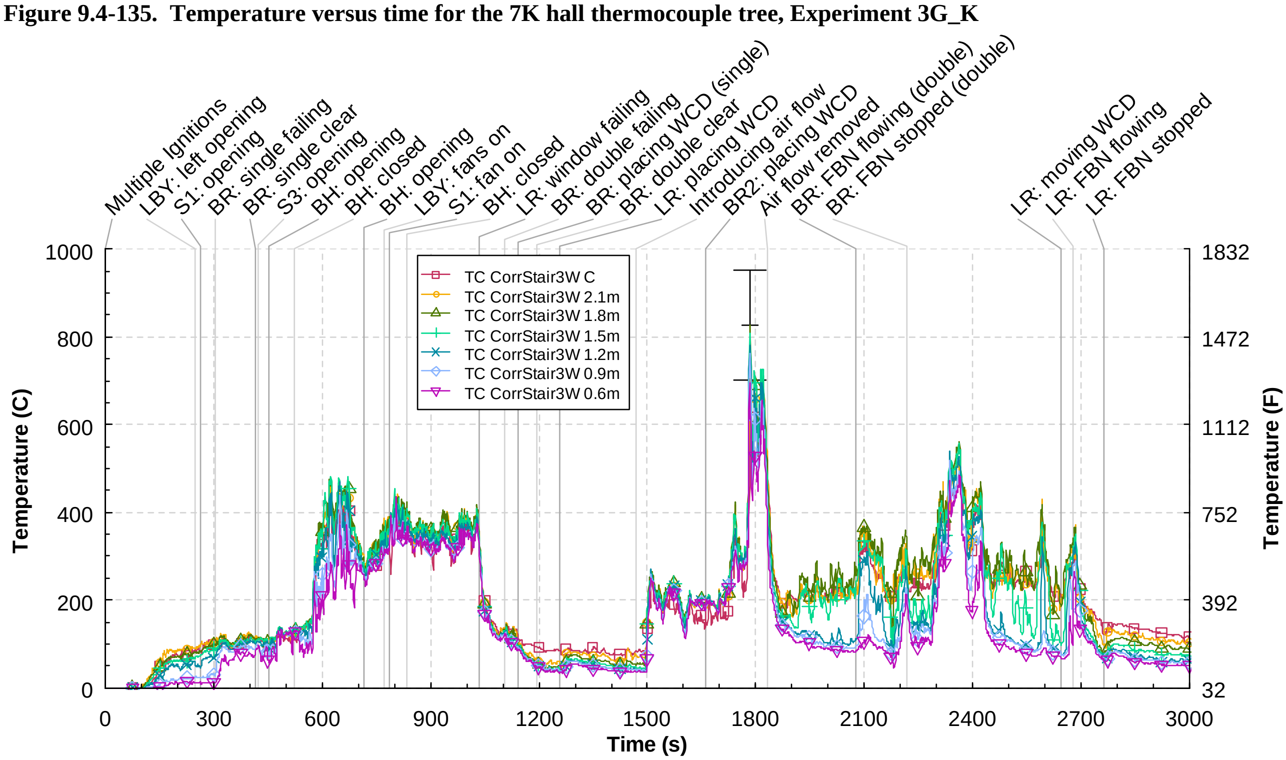



**Figure 9.4-136. Temperature versus time for the 7th floor stair hall thermocouple tree, Experiment 3G_K**

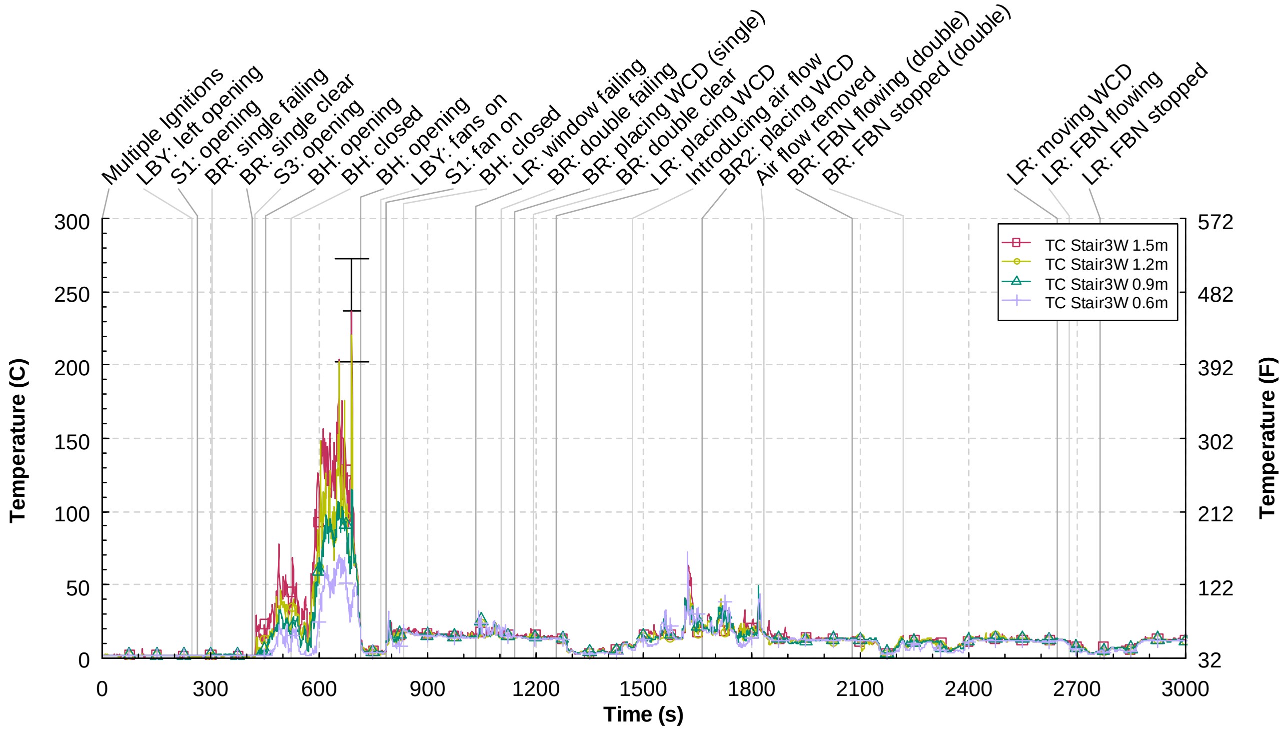



**Figure 9.4-137. Temperature versus time for the 7th floor stairwell thermocouple tree, Experiment 3G_K**

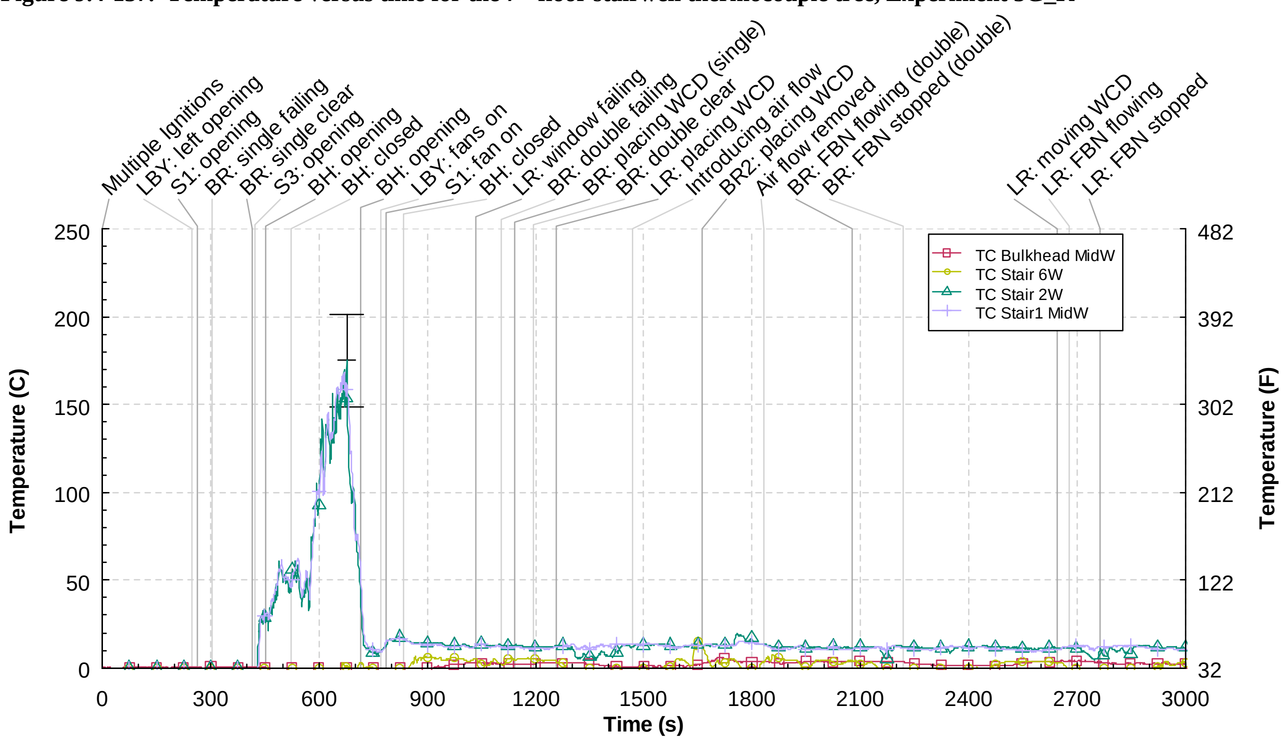



**Figure 9.4-138. Temperature versus time for the stair thermocouples, Experiment 3G_K**

### 9.4.14.2 Pressures

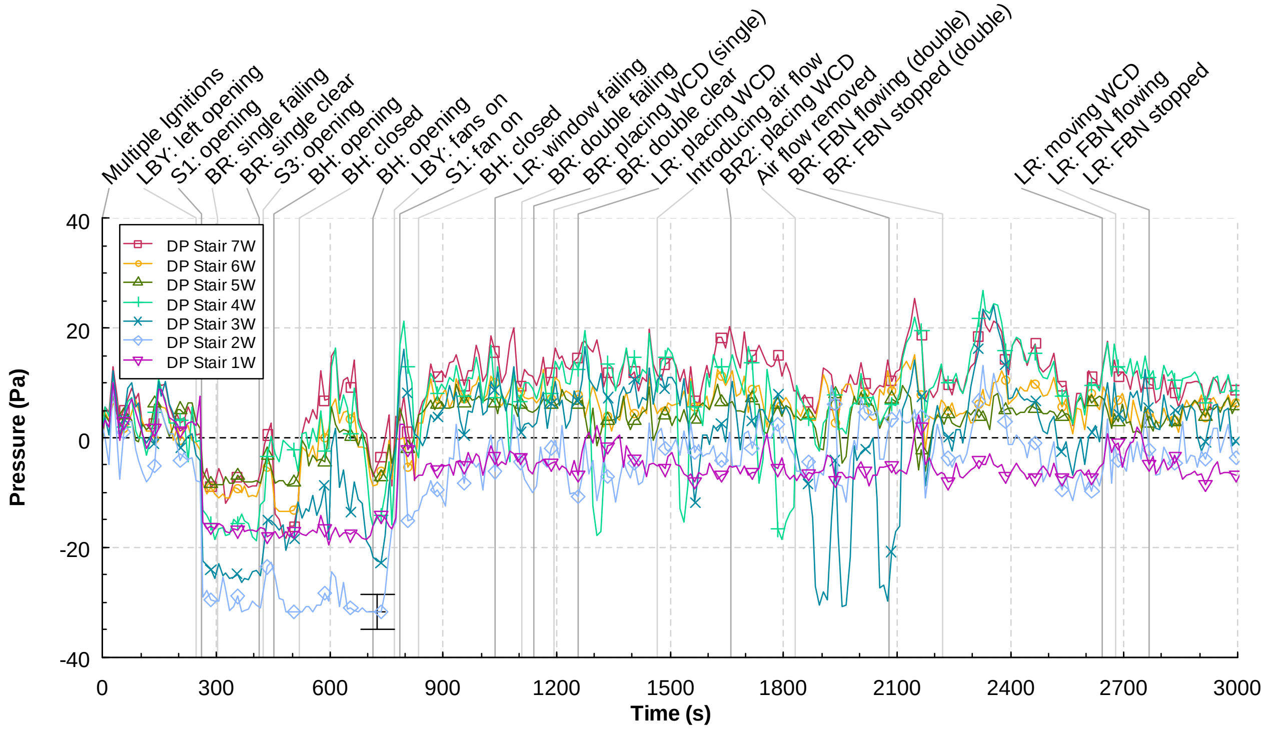



**Figure 9.4-139. Differential pressure versus time for the stairwell bi-directional probes, Experiment 3G_K**

## 9.5 Appendix E – Post Fire Images

### 9.5.1 Apartment 7G

**Figure 9.5-1. 7G apartment entrance**

**Figure 9.5-2. To the corridor from the living room**

**Figure 9.5-3. Down the corridor toward apartment 7K**

**Figure 9.5-4. Through the bedrooms from the living room**

**Figure 9.5-5. 7G apartment entrance**


**Figure 9.5-6. Down the stairwell from the fire floor**

### 9.5.2 Apartment 7E


**Figure 9.5-7. 7E apartment entrance**


**Figure 9.5-8. Living room from entrance**


**Figure 9.5-9. Living room window**


**Figure 9.5-10. Bedroom double window**


**Figure 9.5-11. Bedroom single window**


**Figure 9.5-12. Bedroom single window**

## 9.5.3 Apartment 7A

Figure 9.5-13. Living room window

Figure 9.5-14. Bedroom double window

Figure 9.5-15. Bedroom single window

Figure 9.5-16. Bedroom door from ignition bedroom

Figure 9.5-17. Living room from bedroom-side corner

Figure 9.5-18. 7A apartment entrance from living room

### 9.5.4 Apartment 7K

Figure 9.5-19. Apartment 7K entrance

Figure 9.5-20. Living room from entrance

Figure 9.5-21. Living room to bedroom hallway

Figure 9.5-22. Bedroom 2 window

Figure 9.5-23. Bedroom double window

Figure 9.5-24. Bedroom single window

## 9.5.5 Apartment 5E

Figure 9.5-25. Living room from entrance

Figure 9.5-26. Living room window

Figure 9.5-27. Bedroom windows from adjacent bedroom

Figure 9.5-28. Bedroom double from adjacent bedroom

Figure 9.5-29. 5E apartment entrance from the inside

Figure 9.5-30. 5E apartment entrance from the corridor

## 9.5.6 Apartment 5K


Figure 9.5-31. 5K apartment entrance


Figure 9.5-32. Living room from entrance


Figure 9.5-33. Living room window and kitchen


Figure 9.5-34. Bedroom 2 from hallway


Figure 9.5-35. Bedroom double window


Figure 9.5-36. Bedroom single window

### 9.5.7 Apartment 5A

Figure 9.5-37. 5A apartment entrance

Figure 9.5-38. Living room window


Figure 9.5-39. Living room toward bedroom-side wall

Figure 9.5-40. Living room toward wall opposite window

Figure 9.5-41. Bedroom single window

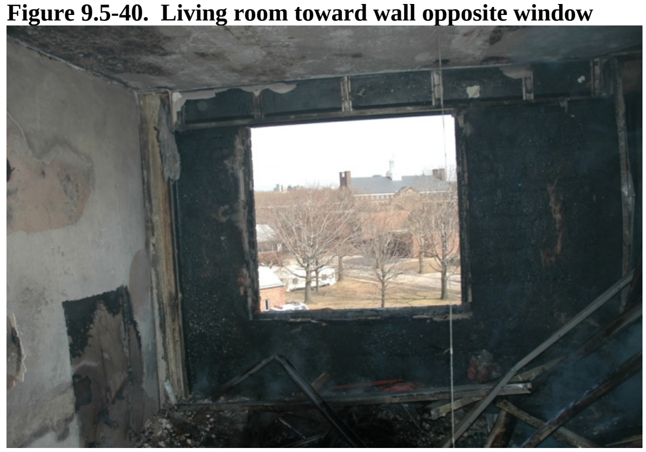


Figure 9.5-42. Bedroom double window

### 9.5.8 Apartment 5G

Figure 9.5-43. 5G apartment entrance

Figure 9.5-44. Toward entrance from living room

Figure 9.5-45. Bedroom 2 from hallway

Figure 9.5-46. bedroom 2 toward hallway

Figure 9.5-47. Bedroom double window

Figure 9.5-48. Bedroom single window

### 9.5.9 Apartment 3A

Figure 9.5-49. 3A apartment entrance

Figure 9.5-50. Living room from entrance

Figure 9.5-51. From apartment door into corridor

Figure 9.5-52. Bedroom double window

Figure 9.5-53. Bedroom single window

Figure 9.5-54. Toward apartment entrance from living room

### 9.5.10 Apartment 3E

Figure 9.5-55. Living room from entrance

Figure 9.5-56. Living room window

Figure 9.5-57. 3E apartment entrance from living room

Figure 9.5-58. Living room to bedroom hallway

Figure 9.5-59. Bedroom double window

Figure 9.5-60. Bedroom single window

## 9.5.11 Apartments 3G and 3K
### 9.5.11.1 3G

**Figure 9.5-61. Living room from entrance**

**Figure 9.5-62. Bedroom double window**

**Figure 9.5-63. Bedroom single window**

**Figure 9.5-64. Bedroom doorway from far corner**

**Figure 9.5-65. Living room through bedroom 2**

**Figure 9.5-66. Living room window**

### 9.5.11.2 Public Corridor

**Figure 9.5-67. Corridor target**

### 9.5.11.3 3K

**Figure 9.5-68. Into corridor from 3K apartment entrance**

**Figure 9.5-69. Living room window**

**Figure 9.5-70. Bedroom 2 window**

**Figure 9.5-71. Bedroom double window**

**Figure 9.5-72. Bedroom single window**

**Figure 9.5-73. Down the corridor from 3K apartment entrance**